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REVIEW SECTION

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IGR TRANSLITERATION OF RUSSIAN

The AGI Translation Center has adopted the essential features of Cyrillic Transliteration recommended by the U. S. Department of the Interior, Board of Geographical Names, Washington, D. C.

Alphabet		transliteration
А	а	a
Б	б	b
В	в	v
Г	г	g
Д	д	d
Е	е	e, ye (1)
Ё	ё	ë, yë
Ж	ж	zh
З	з	z
И	и	i (2)
Й	й	y
К	к	k
Л	л	l
М	м	m
Н	н	n
О	о	o
П	п	p
Р	р	r
С	с	s
Т	т	t
У	у	u
Ф	ф	f
Х	х	kh
Ц	ц	ts
Ч	ч	ch
Ш	ш	sh
Щ	щ	shch
Ъ	ъ	" (3)
Ы	ы	y
Ь	ь	' (3)
Э	э	e
Ю	ю	yu
Я	я	ya

However, the AGI Translation Center recommends the following modifications:

1. Ye initially, after vowels, and after ъ, ь. Customary usage calls for "ie" in many names, e.g., SOVIET KIEV, DNIEPER, etc.; or "ye", e.g., BYELORUSSIA, where "e" follows consonants. "e" with dieresis in Russian should be given as "yo".

2. Omitted if preceding a y, e.g., Arkhangelsky (not iy; not ii).

3. Generally omitted.

NOTE: The well-known place and personnel names that have wide acceptance in international literature will be here adopted. However, German-type transliteration e.g., J for Y will not be used.

STRATIGRAPHY AND PALEOGEOGRAPHY OF THE CARBONIFEROUS AND PERMIAN FORMATIONS OF SIKHOTE-ALIN[1]

by

V. K. Yeliseyeva

• *translated by Research International* •

ABSTRACT

The region now represented by the Sikhote-Alin range was a geosyncline during the Carboniferous nd Permian periods. On the basis of structure and petrology, four zones can be distinguished with- n the area. These are the Olga-Tetyukhinsk, central Sikhote-Alin, southern-coastal, and Grode- ovsk zones. In the Olga-Tetyukhinsk zone, the Permo-Carboniferous section consists of 8, 000 neters of sandstone interbedded with shale, chert, and limestone; and in the central Sikhote-Alin one, is composed of 14, 000 meters of terrigenous sediments interbedded with basic and inter- nediate volcanic rocks. In the marginal southern coastal zone, the upper Paleozoic sequence, pre- ominately of continental origin, records repeated uplift and subsidence. An abundant flora indi- ates continental conditions to have prevailed in the Grodekovsk zone during early Permian time; pper Permian formations are marine, commonly of limestone with interbedded tuff and lava. --Translator.

The mass of material on the stratigraphy of e Khabarovsky territories, coastal and south- rn regions (accumulated principally after the reat Civil War by numerous geologic organiza- ons) as well as results of prolonged studies by ndividual investigators, are sources of certain eneral conclusions regarding stratigraphy and aleogeography of the Sikhote-Alin Carbonifer- us and Permian formations.

The upper Paleozoic formations, which cover onsiderable area in this territory, are not well nown. In particular, stratigraphy of the Olga- etyukhinsk, central Sikhote-Alin, and Grode- ovsk regions is poorly understood. Although nore geologic mapping is needed, it is also mportant to analyze relationships between the arious stratigraphic subdivisions, and to orrelate the Carboniferous and Permian sec- ons throughout structural-facies zones of the ikhote-Alin geosynclinal region.

By synthesis of stratigraphic data, it is ossible to outline the broader paleogeographic f the middle and upper Carboniferous and of e lower and upper Permian. Studies by . F. Maslennikov and M. I. Sosnina, both aleontologists, have been of considerable alue in this effort.

From 1931 to 1940, Maslennikov conducted a pecial study on stratigraphy and paleontology f the upper Paleozoic formations. Prior to is study, the upper Paleozoic section was not ell known, and determinations of the brachio- od fauna had resulted in conflicting correlations. The age of marine and continental formations, according to one group of investigators, was upper Carboniferous; according to other groups, it was lower or upper Permian. Maslennikov studied upper Paleozoic rocks over a considerable area. As a result, the marine series of southern Yuzhnoye Primorye (southern coastal region) were assigned largely to the upper Permian. He distinguished five units in the upper Paleozoic of this area; these, from oldest to youngest, are: 1) chert-shale (radiolarian), 2) continental-marine (upper Suchan), 3) sandstone-limestone (Chandalaz or Doliolin), 4) sandstone-tuff shale (Nakhodkin-Kaluzin), and 5) sandstone-shale (Sitsinsk). Maslennikov tentatively assigned the chert-shale sequence to the upper Carboniferous; the continental-marine (upper Suchan) to the lower Permian, and the others to the upper Permian. Later, new fossils were found (principally foraminifers) which allowed reexamination of the age of these rocks.

Sosnina, in studying the Primorye (seacoast) foraminifers, distinguished lower Carboniferous (Visean), middle Carboniferous (Moscovian), and upper Carboniferous forms. She also indicated that it was possible to divide the lower Permian into two paleontological horizons: the lower containing Pseudofusulina ex gr. vulgaris (Schellw. et Dyhrenf.) and the upper containing Cancellina ex gr. primigena Hayden and Misellina ex gr. claudiae (Deprat.).

It is possible to describe the upper Paleozoic formations of Sikhote-Alin following the structural-facies zones (Olga-Tetyukhinsk, central Sikhote-Alin, southern coastal, and Grodekovsk) observed by investigators in the last few years (table 1). The author adheres basically to regional divisions suggested by N. A. Belyayevsky (1956). Division of structural-facies zones is based on the existence of geosynclinal or similar features in the Carboniferous and Permian. These zones differ sharply from each

[1]ranslated from Osnovnyye cherty stratigrafii i aleogeografii Kamennougolnykh i Permskikh tlozheny Sikhote-Alinya: Sovetskaya Geologiya, o. 5, p. 46-65, 1959.

TABLE 1. Scheme for the correlation of Carboniferous

System	Division	Stage or Sequence	Olga-Tetyukhinsky region: Lithology	Olga-Tetyukhinsky region: Fauna & Flora	Sequence	Central Sikhote-Alin region: Lithology	Central Sikhote-Alin region: Fauna & Flora
PERMIAN	UPPER						
					Shetukhinskaya	Diabase, spillites, diabase porphyries and their tuffs, tuffo-breccias, lava breccias, more rarely tuffites 600-3,000 m	
					Lyudyanzinskaya	Siltstones, argillites and sandstones 2, 300 m	
		Chandalazskaya	Siltstones, fine-grained to coarse-grained sandstones. Beds of siliceous shales and limestones 450 m	Glomospira sp., Ammodiscidae, Nodosaria sp. Pachyphloia sp Endothyra sp. Reichelina sp., (R. aff rhomboidea Sosn.)	Chandalazskaya (Kafenskaya)	Sandstones, siltstones, argillaceous shales, siliceous shales, altered porphyrites Limestones and conglomerates 1,800-2,500 m	Productus vallacei Derby Pr. villiersi var. kozlowskianus Frks., Pr. sp. indet., Pr. humboldti Orb., Camarophoria margaritowi Tsch., C. sp., Spirifer fascigar Keys., Martinia (Martiniopsis) sp. nov., M. sp. indet., Spiriferella rajah Salt., Waagenophyllum cf. indicum. Waag. at Wentz, W. cf. permicum, Landsdaleia cf. vinasse, Nodosaria sp. Pachyphloia multiseptata Lange, Geinitzina aff. pusilla Grozd, Reichelina cf. minuta Erk., R. aff. media M.-Maclay, Parastafella (?) sp. and Misellina sp.

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and Permian formations of Sikhote-Alin

Sequence	South Coastal region Suchan, Maykhe river basins)		Grodekovsky region	
	Lithology	Fauna & Flora	Lithology	Fauna & Flora
Sitsinskaya	Arenaceous-lutaceas sandstones, more rarely, carbonaceous shales. Layers of conglomerate and seams of coal 250-550 m	Sphaenopteris tenuis Schenk., S. lanceolata Radcz. S. sp. Iniopteris arcuata Radcz., Pecopteris anthriscifolia (Goepp) Zal., Callipteris sp. nov. Radcz. (aff. C. polyneura Zal.) Supaia sahnii (Zal.), Radcz, Noeggerathiopsis sutschanica Radcz., N. sp. (ex gr. N. insignus Radcz.) and others.	Pelitic and aleurite carbonaceous tuffs and tuff shales with rare layers of tuff sandstones and psamittic tuffs.	
Nakhodinsko-Kaluzinskaya	Sandstones, siltstones-argillites, tuffaceous sandstones, tuff conglomerates, tuff breccias. Lenses of sandstone. Quartz porphyry porphyrites 800 m	Fenestella cyclofenestrata Condra, Orthotichia rugosa Frcks, Productus kryschtofavichi Frcks. Strophalosia paradoxa Frcks, Spiriferina cristata Schloth., Athyris subexpansa Waag., Lima cf. retifera Schum., Myalina aff. perratenuata Meek.et Hayd.	Quartz porphyry, felsites, their tuffs and tuff shales. Diabase, diabase porphyrites and their tuffs, tuff lavas, tuff sandstones. Lenses of limestones.	Productus (?) sp.
Lyudyanzinskaya	Argillites and siltstones interbedded with sandstones. Layers of conglomerates and limestones 800 m	Spirifer moosakhailensis Dav., Spiriferella cf. saranae Vern, Spiriferella cristata Sch., Marginifera involuta Tsch., Productus mammatus Keys., Pr. ussuricus Frck., Pr. weyprechti Toula, Pr. pseudoartiensis Stuck. Marginifera involuta Tsch., Ammodiscidae, Celaniella ex gr. parva (Kolani)		
Chandalazskaya	Sandstones, siltstones, artillites, argillaceous shales, limestones and conglomerates 700-800 m	Littonia nobilis Waag., Richthogenia lawrenciana Waag., Camarophoria margaritowi Tschern., Spiriferella litha Frcks. Pseudophillipsia sutschanica Veber., Polypora elliptica var. sutschanensis Nikif. Rauserella ellipsoidalis Sosn. Condonofusiella parya Sosn., C. lipovensis Sosn., Lantschichites tenuteca Sosn., L. elegans Sosn., Ussuriella ussurica Sosn., Lepidolina ussurica (Dutk.), Misellina lepida (Schwager) and others. Monodiexodina sutschanica (Dutk.), Misellina lettensis (Schubert) and others.	Sandstones, siltstones, argillaceous shales. Lenses of limestone	Spiriferella litha Frcks. Sp. rajah Salt. Sp. cristata Schloth. Spirifer moosakhallensis Dav., Sp. amliensis Waag., Sp. fasciger Keys., Camarophoria margaritowi Tschern., Marginifera typica Waag., M. involuta Tschern., Productus cf. Kryschtofovichi Tschern., Pr. purdoni Dav., Pr. dagardi Toula, Pr. gratiosus Waag., Paralleodon cf. tenuistriatum Meek. et Worth., Athyris subexpansa Waag. and others

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TABLE 1. Scheme for the correlation of Carboniferous

System	Division	Stage or Sequence	Olga-Tetyukhinsky region: Lithology	Olga-Tetyukhinsky region: Fauna & Flora	Sequence	Central Sikhote-Alin region: Lithology	Central Sikhote-Alin region: Fauna & Flora
						Unconformity	
PERMIAN (Concluded)	LOWER	Sibaygousskaya	Varied grain-size sandstones, argillaceous shales with layers of limestone and siliceous shale 2,180 m	Nodosaria sp., Geinitzina sp., Cancelina ex gr. primigena Hayden, Neoschwagerina inflata Sosn., N. ussarica Sosn. and others.	Khodyskaya	Siliceous shales, chert and jasper with layers of sandstone. Lenses of limestone. 800-2,500 m	Endothyra sp., Triticites (?) sp., Pseudofusulina sp., Paragusulina (?) sp. and Verbeekina (?) sp.
PERMIAN (Concluded)	LOWER	Zarodovskaya	Tuffaceous sandstones, spillites, porphyrites and their tuffs, lenses and beds of siliceous shales and limestones 1,200 - 1,300 m	Ammodiscidae, Pachyphloia sp., Globivalvulina sp., Tetrataxis sp. Miliolidae (?), Misellina cf. claudiae Deprat.	Vesnyanskaya	Black argillaceous shales, phyllitic-argillaceous shales, siltstones, sandstones, interbedded with siliceous shales 1,000 m	Noeggerathiopsis aff. Theodori Zal. et Tschirk. N. cf. subangusta Zal., N. ex. gr. Derzavini (Zal.) Neub., N. cf. longifolia Neub., Pecopteris sp.
PERMIAN (Concluded)	LOWER	Kavalerovskaya	Medium-grained and fine-grained sandstones, argillaceous shales, siltstones and lime limestones 1,500 m	Triticites sp. nov. Pseudofusulina ex. gr. vulgaris (Schellw. et. Dyhrenf.), Schwagerina sp., Acervoschwagerina sp. and others.	Sandagouskaya	Plagoiclase porphyrites, diabase porphyrites, amygdaloidal lavas and their tuffs. Chert and limestone 800-1,500 m	Parafusulina (?) sp., Pseudofusulina sp., Triticites sp., and others.
CARBONIFEROUS	Upper		Fine-grained sandstones, interbedded with argillaceous shales and limestones 800-1,000 m	Triticites aff. sinensis Chen, Tr. cf. stuckenbergi Rauser Tr. ex. gr. whitei Rauser et Beljaev and Tr. ussuriensis M.-Maclay.	Samarkinskaya	Cherts, sandstones, siltstones and limestones 500-700 m	Triticites montiparus (Ehrenb, emend. Moell.), Tr. arcticus (Schellw.) Fusulinella (?) sp., F. cf. subpulchra Putr., F. cf. schwagerinoides and others.
CARBONIFEROUS	Middle		Polymictic sandstones, interbedded with argillaceous shales and limestones 1,200-1,300 m	Fusulinella pulchra Rauser et Beljaev and Fusulina ex gr. cylindrica Fischer.	Merginskaya	Siltstones, sandstones, siliceous shales, porphyrites and their tuffs. Limestones, conglomerates 1,000-1,200 m	Ozawainella ex gr. angulata (Col.), Tuberitina spiroplectammina sp. Endothyra and others.
CARBONIFEROUS	Lower		Sandstones, siltstones, cherts, interbedded with limestones and siliceous-calcareous breccia. Altered intermediate effusives 950-1,150 m	Archaediscus ex gr. parvus Rauser, A. aff. pastulus Grozd. et Led., A. cf. ovides Rauser, Monotaxis sp., Quasiendothyra cf. diserta Leb., Endothyra ex gr. globulus Eichw., Eostaffella breviscula Ganel., E. ex gr. proikensis Rauser, E. ex gr. masquensis Viss. and others.	Ariadninskaya	Sandstones, siltstones, siliceous shales and limestones 4,000 m	Archaediscus sp., Ammodiscus sp., Endothyra sp., Spiroplectammina (?) sp.

(page 2 concluded)

and Permian formations of Sikhote-Alin (Concluded)

Sequence	South Coastal region (Suchan, Maykhe river basins)		Grodekovsky region	
	Lithology	Fauna & Flora	Lithology	Fauna & Flora
	Unconformity		Unconformity ?	
			Black argillaceous shales, siltstones sandstones	Noeggerathiopsis Theodori Zal., N. Derzavinii (Zal.) ? Neub., Paracalamites sp. (cf. P. vicinalis Padz.).
Yuzagolskaya	Argillites, siltstones, sandstones and conglomerates. Seams of coal 700-90 m [Tr. : probably a mistake should be 900]	Lepidodendron sp., Lepidodendron oculus felis	Phyllitic argillaceous shales, siltstones and sandstones 600-1,000 m	
	Siltstones, argillites, sandstones with beds of carbonaceous shales and conglomerates 1,000 m	Leiotriletes microrugosus (Yb. Waltz) Naum., Licuopdizonotriletes inclusus Luber, Zonaletes stipticus Luber and others		

(page 3 concluded)

other in their tectonic, magmatic and sedimentary development.

The Olga-Tetyukhinsk zone is located southeast of the central Sikhote-Alin zone; total thickness of its Carboniferous and Permian section is 8,000 meters (m). It is assumed that this zone was situated in a Permian trough, as indicated by the presence of lower, middle, and upper Carboniferous age and of lower and upper permian age marine formations.

The base of the Olga-Tetyukhinsk section is composed of lower Carboniferous sediments. The lower part consists of gray medium-grained quartz or quartz-feldspar sandstone, interbedded with siliceous and argillaceous shale. The middle part is composed of siliceous and calcareous-siliceous breccia and altered tuff (porphyrite or dacite) with large accumulations of white, massive limestone containing Visean foraminifers (Archaediscus ex gr. parvus Raus., A. aff. putulus Grozd. et Leb., Endothyra ex gr. globulus Eichw., Eostafella breviscula Ganel., and others). The upper part consists largely of siliceous shale and breccia interbedded with fine-grained sandstone and argillaceous shale. Total thickness of the lower Carboniferous ranges from 950 to 1,150 m.

The middle Carboniferous (1,200 to 1,300 m thick) is represented by a thick series of sandy shale containing lenses of limestone and siliceous shale. In the limestone cut by Tadush river (above Kavalerovskaya Cliff), foraminifers of late-middle Carboniferous age have been found (including Fusulinella pulchra Raus et Beljaev, Fusulina ex gr. cylindrica Fisch.; species typical of the Moscovian stage of the Russian platform).

The upper Carboniferous, developed at Sankin spring, consists of a thick sandstone-shale sequence with limestone lenses containing foraminifers (Triticites aff. sinensis Chen, Tr. cf. stuckenbergii Raus, Tr. ussuricus M. Macl., Tr. ex gr. whitei Raus et Beljaev, and others), typical of the lower part of the upper Carboniferous. This series is 800 to 1,000 m thick.

The Carboniferous formations are conformably overlain by three lower Permian divisions. The lower part of the section, the Kavalerovskaya sequence is composed of sandstone and argillaceous, arenaceous-argillaceous, and siliceous shale. The basal limestone contains foraminifers typical of the lower half of the lower Permian (Pseudofusulina ex gr. vulgaris (Schellw. et Dyhrenf.), Pseudofusulina sp., and others). The Kavalerovskaya sequence is over 1,500 m thick. The middle part of the section, the Zarodovskaya sequence (including the Zarodovskaya and Pantovy sequences [17]), consists of limestone, tuffaceous sandstone, siliceous and argillaceous shale, siltstone, and amygdaloidal lava. The limestone along the northern flank of Zarod mountain contain Misellina ex gr. claudiae (Deprat.), Lagenidae indet., Tetrataxis sp., and other foraminifers corresponding to the upper part of the lower Permian. The Zarodovskaya sequence is 1,200 to 1,300 m thick.

The upper part of the section, the Sibaygousskaya sequence, consists principally of graywacke intercalated with limestone and siliceous shale. The limestone contains Cancellina ex gr. primigena Hayd., Neoshwagerina inflata Sosn., and other foraminifers peculiar to the upper part of the lower Permian and, possibly, to the lower part of the upper Permian. Thickness of this unit is 2,180 m.

The section is terminated by upper Permian siltstone, sandstone interbedded with argillaceous shale, siliceous shale, and limestone. The upper Permian contains fossils similar to those of the upper Permian in the southern coastal region, including Ammodiscidae, Reichelina sp., Orientella (?) sp., Codonofusiella (?) sp., and others. Thickness of the upper Permian is 450 m.

The upper Paleozoic section in more western regions is considerably thicker (approximately 6,000 m) than in the Zarod mountain region (4,000 m).

The Kavalerovskaya cliff region was subjected to prolonged downwarping throughout the Carboniferous and Permian; accompanied by deposition of relatively homogeneous sandstone intercalated with argillaceous and siliceous shale and limestone. Sediments of volcanic origin are not present. Spillite and amygdaloidal porphyrite, common in the Zarod mountain region, apparently mark ancient volcanos which coincide with major fractures. In the Sibayrou river basin, which occupies an intermediate position between the Kavalerovskaya cliff area and the Zarod mountain region, rocks of volcanic origin are of limited thickness.

The central Sikhote-Alin zone, a strongly downwarped sector of a geosynclinal region, is composed of 14,000 m of Carboniferous and Permian siliceous extrusives and terrigenous sediments. At the base of the Paleozoic section, in the Sikhote-Alin zone, is a very thick (over 1,000 m) terrigenous sequence, possibly corresponding to V. G. Beloussov's (Tr. sic) so-called "lower terrigenous formation;" this series apparently corresponds to the beginning of geosynclinal development in the Sikhote-Alin region. The entire region is characterized by extensive development of basic and intermediate extrusives, and by presence of chert.

The axial area of the central Sikhote-Alin uplift is composed primarily of Carboniferous

sediments; Permian formations occur to the east and west. Absence of good sections, paucity of fossils and lack of detailed stratigraphic studies permits only a generalized description of this area.

The Carboniferous section has at its base the thick Ariadninskaya sequence, composed of sandstone, siltstone, phyllite-shale, siliceous shale, and limestone. Foraminifers have been found in the limestone (in the watershed of Levaya Sinancha and Erldagou rivers). Presence of Archaediscus indicates that the limestone can be either late-lower or early-middle Carboniferous.

Overlying the Ariadninskaya sequence is of the Merginskaya sequence, consisting of siltstone, sandstone, chert, porphyrite and tuff, limestone, and conglomerate. In limestone beds between outcrops of extrusive rocks (in the watershed of Merga and Arsentyevaya rivers), Ozawainella ex gr. angulata (Col.), Tubertina sp., Spiroplectammina sp., Endothyra sp., and other foraminifers have been found. Presence of Ozawainella indicates that the limestone is most probably of early-middle Carboniferous age. Thickness of the Merginskaya sequence is approximately 1,000 to 1,200 m.

Conformably above the Merginskaya sequence is that of Samarkinskaya consisting of chert (predominating) and interbedded sandstone, siltstone and limestone. The limestone within the chert beds (Samarka peninsula) contain Triticites montiparus (Ehrenb., emend. Moell.), Tr. arcticus (Schellw.), Fusulinella (?) sp., F. cf. schwagerinoides Depr., and others. Triticites montiparus and Tr. arcticus indicate the age of the Samarkinskaya sequence to be upper Carboniferous. This unit is 500 to 700 m thick.

The Carboniferous is overlain by lower Permian marine and continental rocks; change from continental to marine deposition occurs from west to east. In the east, the section contains thick accumulations of chert and porphyrite extrusives, together with limestone lenses that locally contain foraminifers.

Comparing the various sections, it is possible to subdivide the lower Permian of the central Sikhote-Alin zone into three parts. These differ from one another in mineral composition, microfauna, and flora.

The lower part of the section, called the Sandagouskaya sequence in this study, is composed of sandstone, siltstone, plagioclase porphyrite, amygdaloidal lava, and tuff, as well well as chert and limestone. This sequence is widespread and can be traced from the Ulakhe river basin in south to the Khor river basin in the north. On the right banks of Sandagou and Sebuchara rivers, limestone beds contain lower Permian microfauna: Parafusulina (?) sp., Pseudofusulina sp., Triticites sp., and others. Thickness of this sequence ranges from 800 to 1,500 m.

Next in the stratigraphic section is the Vesnyanskaya sequence, composed of black argillaceous shale, argillaceous-carbonaceous shale, siltstone, and sandstone; it contains (in the upper reaches of the Vesnyanki river, 5 kilometers (km) from the Lespromkhoza Keskhin spur) lower Permian flora (Noeggerathiopsis aff. theodori Zal et Tschirk., N. cf. subaugusta Zal. N. ex gr. derzavinii Neub., Cordaites principalis Germar, and others. Thickness of this sequence exceeds 1,000 m.

Still higher in the section lies the Khodyskaya sequence, unique in its high jasper and chert content. In a breccia, located north of the Vakhumbe peninsula, remnants of the following foraminifers were found: Pseudofusulina sp., Parafusulina (?) sp., Triticites (?) sp., Verbeekina sp.; late lower Permian age is indicated. Thickness of the sequence ranges from 600 to 800 m in the south; and possibly, as much as 2,500 m thick in the central part of the central Sikhote-Alin zone (along Bikin river).

Above the lower Permian sequences lies a complex of upper Permian formations composed of marine sediments in the lower part (conglomerate, sandstone, and limestone with abundant brachiopods, bryozoans, and foraminifers). Upward in the section, clastic material becomes progressively finer. Near the end of the Permian, extensive basic and intermediate lavas were extruded.

On the basis of petrographic composition, three sequences can be distinguished in the upper Permian: 1) Kafenskaya sandstone-limestone; 2) Lyudyanzinskaya, primarily siltstone; and 3) Shetukhinskaya sediments and extrusives (the youngest).

The structure of the Kafenskaya sequence is analogous to that of the Chandalazskaya sequence of the southern coastal region. It is composed of sandstone, shale, siltstone, and limestone containing brachiopods, bryozoans, corals, and foraminifers; faunal associations characteristic of the upper Permian of the southern coastal region. In the western section of the central Sikhote-Alin zone, the Kafenskaya sequence is composed almost exclusively of terrigenous rocks (conglomerate, sandstone, shale) and, rarely, limestone, in the eastern section, large accumulations of siliceous and extrusive rocks occur. Thickness of this sequence ranges from 1,800 to 2,500 m.

The Kafenskaya sequence is overlain conformably by the Lyudyanzinskaya sequence,

composed, primarily, of siltstone, argillite, and sandstone (as in the more southern sectors of the Trudnyy peninsula). This sequence may be as much as 2, 300 m thick.

The upper Permian section is completed by the Shetukhinskaya extrusives and sedimentary rocks; it contains tuff intercalated with siltstone, argillite, and, more rarely, sandstone possibly containing admixtures of tuffaceous material. Thickness of the sequence ranges from 600 to 800 m in the north (Kafe river basin), and from 2, 000 to 3, 000 m in the south (Ulakhe and Daubikhe river basin).

From early Carboniferous time, continuing almost without interruption through the end of the Permian, the central Sikhote-Alin zone comprised a marine environment. Only in the Vesnyanka river region at the western margin of the geosynclinal trough, does a lower Permian continental series approximately 1,000 m thick, appear. Volcanic activity was well developed in the upper Paleozoic of the central Sikhote-Alin zone. Sills and lenticular deposits of basic and intermediate volcanics can be traced almost throughout the entire Carboniferous and Permian: For the most part, these are diabase, diabase porphyry, and porphyrite. These rocks are associated principally with the marine series. Near the top of the upper Paleozoic section, acid extrusives, probably of terrigenous origin (Tr. : continental origin) appear.

The Yuzhnoye Primorskaya (Tr. : hereafter referred to as the southern coastal region) zone was subjected to repeated uplift and subsidence during the late Paleozoic. Here, thickness of Carboniferous and Permian formations is less than that of the Olga-Tetyukhinsk and central Sikhote-Alin zones (4,200 to 4,750 m); also, this zone has a different facies composition. Neither thick extrusives (spillites and diabase) nor cherts and jasper are present. The most typical rocks in the southern coastal region are siltstone, sandstone, conglomerate, limestone, and carbonaceous shale. Tuffaceous and extrusive rocks are encountered rarely. These characteristics indicate that this zone occupied, during the late Paleozoic, a marginal position in respect to the geosyncline.

The base of the section is composed of lower Carboniferous greenish-gray siltstone, argillite, and sandstone interbedded with coal, carbonaceous shale, and conglomerate. In siltstone and sandstone of the Tudagou river valley, the Maykhinskaya valley, and along the Vostochnyy and Serebryanyy spurs, numerous spores have been found of Lycopodizonotriletes subtilis Luber, Angaropteritriletes pallens Luber, Zonaletes glyphus Andr., Cycadofulicitreletus serupens Luber, Trematozonotiletes gibberosus (Waltz) Naum, Tr. bialatus (Waltz) Naum. The lower Carboniferous is approximately 1,000 m thick. Higher up the stratigraphic column is the continental Yuzagolskaya sequence containing (west of Nakhodka bay, and in the Erldagou river valley) an upper Carboniferous flora: Lepidodendron oculus felis (Abbado) Zeill., Lepidodendron sp., and others. The sequence, composed principally of sandstone, siltstone, argillite, and argillaceous and siliceous shale, with some coal seams and conglomerate lenses, is 700 to 900 m thick.

Lower Permian formations in the southern coastal zone are absent. All the older formations are overlain unconformably by upper Permian formations, composed of limestone, siltstone, argillaceous shale, sandstone of various composition, conglomerate, and extrusives (quartz prophyry and tuff). A feature characteristic of the upper Permian formations is frequent interfingering of terrigenous sediment and carbonate rocks. The fossils of the upper Permian formations are abundant and varied, with brachiopods, foraminifers, and bryozoans of most common occurrence. Characteristic are the highly specialized brachiopod groups Lyttonia and Richthofenia, and fusulinids of the Misellina type.

Analysis of upper Permian cross sections of the southern coastal region and comparison of stratigraphic columns compiled by various authors (Maslennikov, Belyayevsky and V. D. Prinada, Sosnina, V. V. Kulikov, and N. M. Organova) indicates division of the upper Permian into four sequences: 1) Chandalazskaya limestone-sandstone, 2) Lyudyanzinskaya sandstone-siltstone, 3) Nakhodkinsko-Kaluzinskaya extrusives and tuffaceous sediments, and 4) Sitsinskaya sandstone-shale. These sequences, retaining their individual characteristics within the southern coastal region, can be correlated as well with formations in the Grodekovsk zone, and partially with formations of the central Sikhote-Alin and Olga-Tetyukhinsk zones.

The Chandalazskaya sequence is composed of sandstone, limestone, argillaceous shale, siltstone, and conglomerate. The limestone contains abundant brachiopods, pelecypods, gastropods, trilobites, bryozoans, corals, and foraminifers; all typical of the upper Permian. The sequence is 700 to 800 m thick.

The Lyudyanzinskaya sequence is composed of compact pyritized argillite and siltstone, interbedded with sandstone and conglomerate in its lower part. The argillite and siltstone contain brachiopods (productids and spirifers); more rarely, gastropods and pelecypods. Higher in the section are sandstone and siltstone of various colors, and a thick layer of conglomerate. The section is completed by shaly argillite and siltstone, locally containing pelecypods. Colaniella ex gr. parva (Colani)

has been found in a thin bed of gray crinoidal limestone. The thickness of the sequence is 500 to 600 m.

The Nakhodinsko-Kaluzinskaya sequence is a series of tuffaceous sandstone, siltstone, argillite, tuffaceous conglomerate and breccia (dacite and plagioclase porphyrite). A rich upper Permian fauna has been found in the tuffaceous formations of Cape Kaluzin. The thickness of the sequence is 250 to 550 m.

The Sitsinskaya sequence completes the upper Paleozoic section of the southern coastal zone. It is composed of sandstone with various rock fragments, carbonaceous and sandy-carbonaceous shale, a coal seam, and conglomerate lenses. The sequence is from 200 to 550 m thick.

The southern coastal zone is characterized by a relatively thin accumulation of sediment, principally of continental origin. In spite of varied lithologic composition of the upper Permian formations and, of frequent alternation of sedimentary and volcanic rocks (particularly in the upper part of the section), the environment in existence during deposition of the upper Permian sediments can be characterized, on the whole, as that of shallow water. This is indicated by numerous conglomerate concentrations, abundance of sandstone, and secondary importance of siltstone and limestone. The regressive nature of the section is recognizable in that relatively deep marine sediments were replaced by shallow-water and littoral formations in the upper parts of the section. There is an increase in amount of volcanic material from the base to the top of the sequence.

The Grodekovsk zone, situated at the eastern margin of the Ussuri-Khankaysky massif, is characterized by upper Paleozoic formations similar to those of the same age in the other three zones. Thickness of the upper Carboniferous and lower Permian is much less (from 600 to 700 m). During the late Permian, downwarping was considerable; total thickness of sediments in this zone is approximately 6,000 m. Abundant fossil plants in the lower Permian rocks indicate prevailing continental environment. The upper Permian formations are marine, consisting commonly of limestone, in association with tuffaceous and extrusive rocks.

Upper Paleozoic rocks of the Grodekovsk zone have been little studied: Absence of complete sections, intensive dislocation of the strata, and the lack of sufficient outcrops have obstructed their stratigraphic interpretation and classification.

The base of the section is composed of upper Carboniferous (?) formations composed for the most part, of argillaceous shale, aleuropelite, and siltstone. As these rocks are overlain conformably by a series containing lower Permian plants, the age of these rocks is determined provisionally to be upper Carboniferous; their thickness ranges from 600 to 1,000 m.

Next to the stratigraphic section is a continental sedimentary series containing a lower Permian flora (Sintukher): Noeggerathiopsis theodori Zal, Noeggerathiopsis derzavinii Neub., and others. This 300-m thick series is composed principally of sandstone interbedded with black, carbonaceous-argillaceous shale.

Above lies a complex of upper Permian marine sediments containing numbers of brachiopods, bryozoans, and foraminifers. The proportion of volcanic material increases going upward in the series; lava and fragmental strata of volcanic origin are more than 2,000 m thick. In late Permian time, continental sediments were deposited (pelitic and aleuritic carbonaceous tuff and tuffaceous shale).

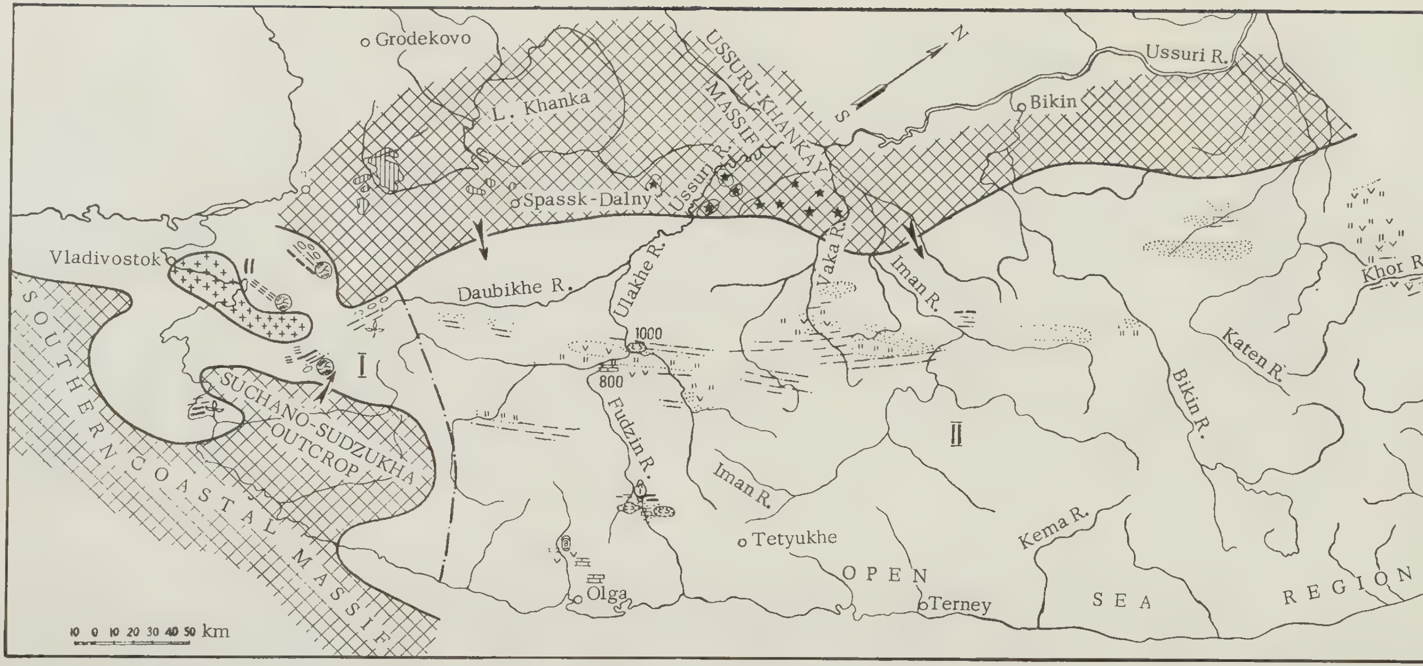
In the upper Permian, three series can be distinguished on the basis of lithologic composition. The lowest, a sandstone-shale sequence, contains some limestone, argillaceous shale, and aleuropelite. The limestone contains a large brachiopod, bryozoan, and coral fauna characteristic for the upper Permian in the southern coastal zone.

The middle sequence, an extrusive-tuffaceous rocks is composed largely of intermediate and basic lava, their tuffs, tuffolavas, and lava breccias, all interbedded with tuffaceous sandstone and shale, and limestone lenses. Higher in the section, the basic extrusives are replaced by more acidic varieties: quartz porphyry and felsite, intercalated with sediments and siliceous-tuff and tuffaceous-shale accumulations. In limestone, northeast of Voroshilov, poorly preserved coral remains were found; and, on the left slope of Mramornyy spring, brachiopods (productids). The section is 2,300 to 2, 400 m thick.

The upper Paleozoic section of the Grodekovsk zone is completed by a tuffaceous sandstone-shale series consisting of psammite tuff, tuffaceous sandstone, tuffite, and pelitic and carbonaceous tuffaceous shale.

The sedimentary section of the Grodekovsk zone is thin, and predominantly continental; marine deposits are confined to the upper Permian. In the southern part of this zone (Barabashsky region), the upper Permian marine series apparently lies directly on crystalline Precambrian rocks and, on other older (middle Paleozoic) granites.

As a result of stratigraphic studies on the



ancient land area (permanent uplifts, subjected to prolonged degradation

Archean gneiss and crystalline schist

Cambrian carbonate and terrigenous series

degradation areas (non-permanent)

spillite, diabase porphyrite, diabase (regions of vulcanism)

limestone

sandstone

interbedded sandstone and siltstone

siltstone and argillite

siliceous shales and jasper

siliceous-carbonaceous and carbonaceous shale

conglomerate

coal

Kataziatskaya-type flora

Carboniferous spores

limestones containing Eostafella and Millerella (Visean stage)

Ozawinella ex gr. angulata and Eostafella (Bashkirian stage)

limestone with Fusulinella and Fusulina (Moscovian stage)

limestone containing Triticites (upper Carboniferous)

main directions of clastic-sediment transportation

Zone borders

FIGURE 1. Paleogeographic map of the Sikhote-Alin region during the middle and late Carboniferous
I. Southern coastal zone: region of limited marine-sedimentary deposition (conglomerate, sandstone, and carbonaceous-argillaceous shale predominate); II. Central Sikhote-Alin zone and Olga-Tetyukhinsk zone: marine sediment of intermediate thickness (sandstone and siltstone predominate).
Numbers are formation thickness, in meters.

upper Paleozoic formations of the large Sikhote-Alin territory, some generalizations can be made on strata accumulated in troughs of this region during the Carboniferous and Permian periods. New data have appeared recently in the literature on structure of the lower part of the lower Sikhote-Alin lower Paleozoic section (V. K. Yeliseyeva, 1957). Lower Carboniferous argillaceous shale, quartzite, chert, and limestone containing a lower Carboniferous fauna were first formed in the watershed area of Erldagou and Levaya Sinancha rivers. Considering earlier finds of a Visean fauna in limestone beds near Skalisty spring (Olga-Tetyukhinsk zone) (G. P. Volarovich, 1932; N. S. Podgornaya and A. I. Zhamoyda, 1956), as well as an Upper Devonian fauna in northern China near the Soviet border, it is possible that the Sikhote-Alin geosyncline existed at the end of the Upper Devonian and, at the beginning of the lower Carboniferous epochs. However, data on Upper Devonian and lower Carboniferous paleogeography are meagre and divergent. More complete information is available for the middle and upper Carboniferous, and for the Permian. A paleogeographic scheme depicting geographic environment and, in part, geologic structure of the Primorsky and the southern part of the Khabarovsky territories is attempted here: Distribution of land and sea, areas of ancient volcanic activity, and principal lithologies, as well as fossil-collecting localities, are shown.

Isopachous maps, giving the approximate distribution of various depressions in the earth's crust of the Sikhote-Alin region, were prepared for the lower and upper Permian sequences. The paleogeographic scheme for the upper Permian depicts geologic structure of the major degradation zones (Ussuri-Khankaysky massif).

Material on the distribution of facies of middle and late Carboniferous age is scarce (see fig. 1, p. 10); however, principal facies types persisted, for the most part, during the upper Paleozoic. Thus, in the southern coastal region (Shkotovsky region), coarse clastics composed largely of sandstone and conglomerate interbedded with black carbonaceous shale and coal seams outcrop. In the Maykhinskaya valley, along Tadagou and Erldagou rivers, the base of the Carboniferous is conglomeratic; and along the left tributaries of the Vostochnyy (southeast of Artema), argillaceous shale and sandstone were found containing remnant lepidophytes; this indicates prevalence of a moist, warm climate.

The conglomerate, distributed near the ancient shoreline, is not very thick (1.7 to 2 m); the pebbles vary in roundness. Judging from their composition, the conglomerates were eroded from ancient arid highlands (Suchansky and Sudzikhinsky regions) consisting of Archean schist, granite gneiss, and pre-Carboniferous granite. Probably, these uplifts of older rocks comprise the northeastern margin of the extensive Yuzhnoye Primorsky massif, whose bulk is submerged in the Japanese sea. The existence of this massif is deduced not only from presence of ancient gneiss and schist in the southern coastal area, but from gravimetric observations as well. The northernmost part of the massif was named by the authors, the Suchano-Sudzikhinsky salient.

A second degradation area, situated west of the region investigated, is the Ussuri-Khankaysky massif of Archean and Proterozoic rocks striking northwest, and of Cambrian and Sinian rocks striking north. The Archean and Proterozoic structures have no clearly developed folds; rather, they are large steeply dipping monoclines. Only minor folds and corrugations were noted.

Sedimentation during Cambrian and Precambrian time resulted in formation of thick accumulations of shale, calcareous-shale, and flysch series, as well as of spillite-keratophyre. (The flysch occurs on Chernigovka peninsula.)

It is probable that island uplifts covered by Carboniferous vegetation, stretched between the Ussuri-Khankaysky massif (southeastern part) and the Suchano-Sudzukhinsk salient. Deposition of plant remains, subsequently transformed to carbonaceous matter, occurred on coastal plains of the islands and the continent.

Data on middle and upper Carboniferous sediments in the Grodekovsk zone are almost completely lacking. Deposition of argillaceous material near outcrops of ancient granites indicates the western margin of the Ussuri-Khankaysky massif to have been depressed. This massif occupied a considerably larger area during the Carboniferous, than in the succeeding Permian period.

The available information on distribution of sediments in the central Sikhote-Alin zone suggests that, during the middle and late Carboniferous, the environment of this region was different from that of the southern coastal zone. Yellow and green medium- and coarse-grained polymictic sandstone and siltstone are disbtributed in sectors along the ancient shoreline (the right bank of the Daubikhe river in its upper reaches, and northward along the Matay river). The sandstone consists of plagioclase grains, quartz, and acid extrusive rock. Farther east, cherty shale with radiolarians and limestone containing foraminifers are associated with a volcanic series of spillite, diabase, diabase porphyrite, and their tuffs. The bulk of the extrusives was deposited under water; this was evidence by alternation of marine-sedimentary and volcanic series (Fudzin river basin and others).

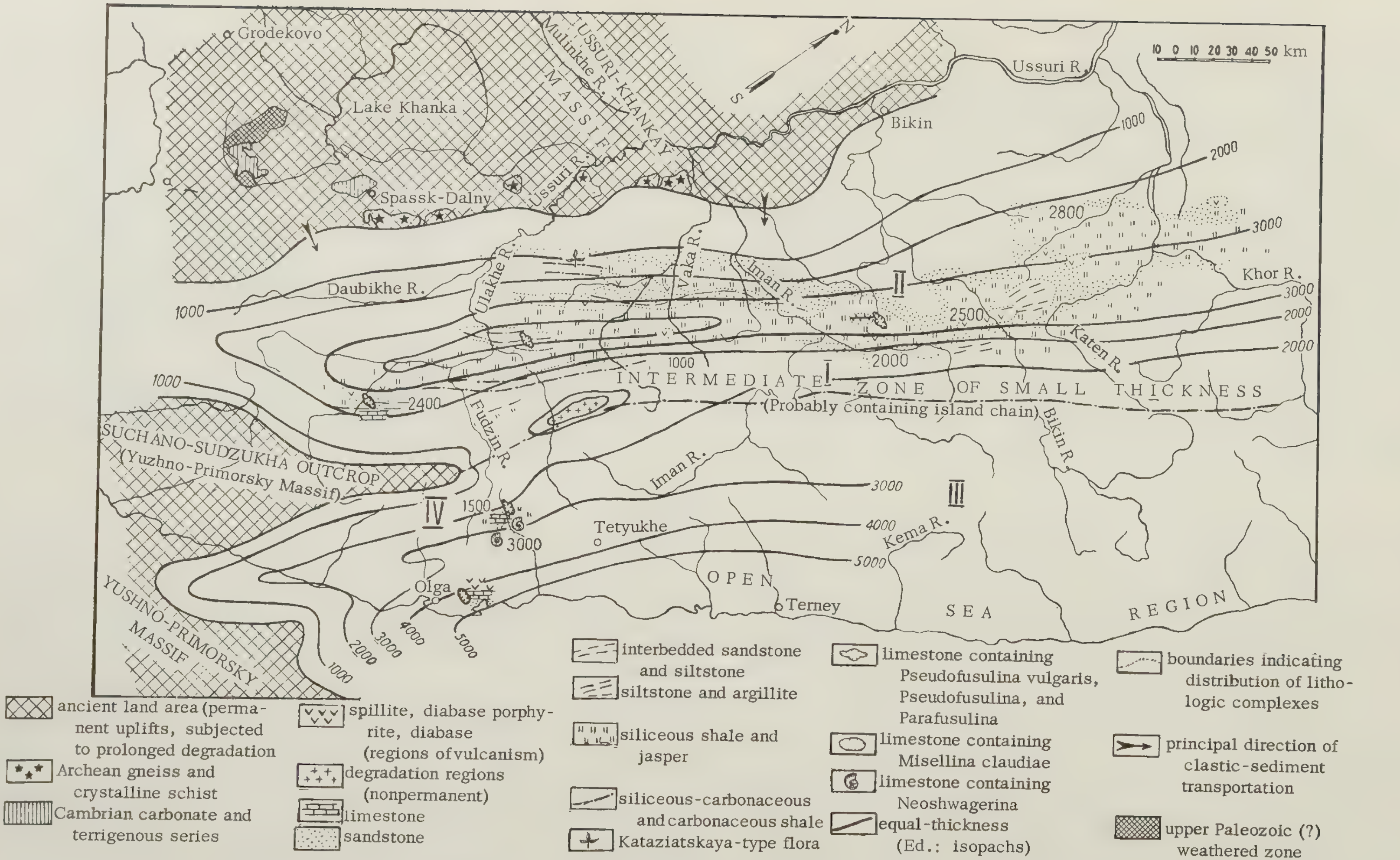


FIGURE 2. Paleogeographic map of the Sikhote-Alin region during the early Permian

Central Sikhote-Alin zone: I. Region of thick marine formations; II. predominantly siliceous formations; III. region of widely developed underwater vulcanism; IV. Olga-Tetyukhinsk zone: region of thick marine formations (sandstone and limestone of various grain size predominate; products of under water vulcanism are developed to a smaller extent) Ed.: IV does not appear in original; inserted here as probable location. Those numbers not related to isopachs indicate total thickness (m) of formations.

The available data do not show whether the Olga-Tetyukhinsk trough [Tr.: depression] was separated from the central Sikhote-Alin zone by a narrow uplift in middle and late Carboniferous time (as clearly indicated for the early Permian); the two areas may have formed a single, major trough. It can be said only that facies of the middle and upper Carboniferous formations of the Olga-Tetyukhinsk region (carbonate, volcanic) are similar to those in the central Sikhote-Alin zone.

In the lower Permian, the general plan of troughs and uplifts remained the same (fig. 2, p.12). However, downwarping of the central Sikhote-Alin geosynclinal trough was more pronounced: If the middle and upper Carboniferous sediments were 1,000 to 1,500 m thick, then, in the lower Permian, the trough was 3,500 to 4,500 m thick. The thickness distribution indicates existence of a second major trough, the Olga-Tetyukhinsk, where the sediment thickness exceeded 4,000 m.

Between these two troughs (central Sikhote-Alin and Olga-Tetyukhinsk), sediment thickness is considerably less; it is here that a chain of islands may have existed. The Suchano-Sudzikhinsky salient increased in size, during the early Permian, in comparison with its Carboniferous configuration; here, lower Permian sediments are missing.

During early Permian time, the siliceous and volcanic series in the central Sikhote-Alin zone was developed to an even greater extent than during the Carboniferous. Siliceous and tuffaceous extrusives were deposited for hundreds of kilometers along the trough axis. A sharp facies change occurs in these sediments, along both strike and dip; lava and tuff of diabase, spillite, and porphyrite are replaced by tuffaceous sandstone, siltstone, chert, and jasper.

Geologic data used in compilation of the paleogeography of the lower Permian indicate that siliceous sediments containing radiolarians were deposited 50 to 60 km from the ancient shoreline. The radiolarian sediments were deposited, either at the margin of the continental shelf, or on the very edge of the continental slope where ocean depth did not exceed 200 m.

Some of the siliceous rock, perhaps a considerable part of it, is related to underwater volcanic activity; frequently, these rocks contain manganese and iron oxides. P. N. Kropotkin noticed small accumulations of iron and manganese oxides in the upper Paleozoic siliceous shale approximately 20 km northwest of Olga bay; in the upper Shirokaya valley; in a tributary of the Arzamasovka river; and, in the Skalistaya valley, 1 to 3 km from its confluence with the Avvakumovka river.

Limestone containing foraminifers typical of the Tethys zone indicates a warm climate for an early Permian epoch; indicated, as well, by paucity of radiolarians and thinness and frailness of their skeletons. Siltstone and sandstone (Khannkheza river basin), containing plant remains, appear to increase in volume closer to the shore. Flysch deposits, characteristic of the upper part of the upper Permian, are absent.

Analogous deposition conditions occurred in the Olga-Tetyukhinskaya zone. As is apparent from the lithologic-stratigraphic profile (fig. 3, see p.14), prolonged downwarping occurred along the Zarod mountain-Kavalerovsk peninsula line; it was accompanied by deposition of sandstone, argillaceous and siliceous shale, limestone, and extrusive rocks.

The section changes from west to east: In the Kavalerovskaya cliff region, sandstone, interbedded with argillaceous and siliceous shale and limestone, was commonly deposited during early Permian time. Strata of volcanic origin are nonexistent. To the east, volcanic in the Sibaygou river basin; farther to the east, in the Zarod mountain region, spillite, amygdaloidal porphyry, and chert are widely distributed. Apparently this region coincides with the location of ancient volcanos developed along major faults.

In the Grodekovsk zone, lower Permian sediments, were eroded almost entirely subsequent to deposition. Only in the Sintukhi river basin on Reshetnikovo peninsula (Mogilnyy spring) do significant deposits of terrigenous sediments outcrop (more than 1,000 m, according to Yu. Ya. Gromov, 1953); these are composed primarily of sandstone. Argillaceous rocks with plant remains are rare. Apparently, to the south and southwest of Lake Khanka the marine regime was intermittent.

In the Sikhote-Alin and adjacent regions, extensive areas were subjected to the upper Permian marine transgression. The sea covered the southeastern Ussuri-Khankaysky massif and the northern margin of the Yuzhnoye-Primorsky massif. However, conglomerates within the upper Permian basalt outcropping along the Sea of Japan Coast (from Abrek bay to Muravyeva-Amursky peninsula) contain, in many instances, pebbles of Precambrian crystalline rock (granite-gneiss and granite). Coarse-grained clastic rocks, moreover, are distributed along the Suchana river banks; this suggests the presence of individual islands in the Dadyan-Shan range and Arkhipovki peninsula regions. Conglomerate developed along the left bank of the Daubikhe river, indicates presence in the vicinity of an upper Permian seacoast.

Land and sea distribution during the upper

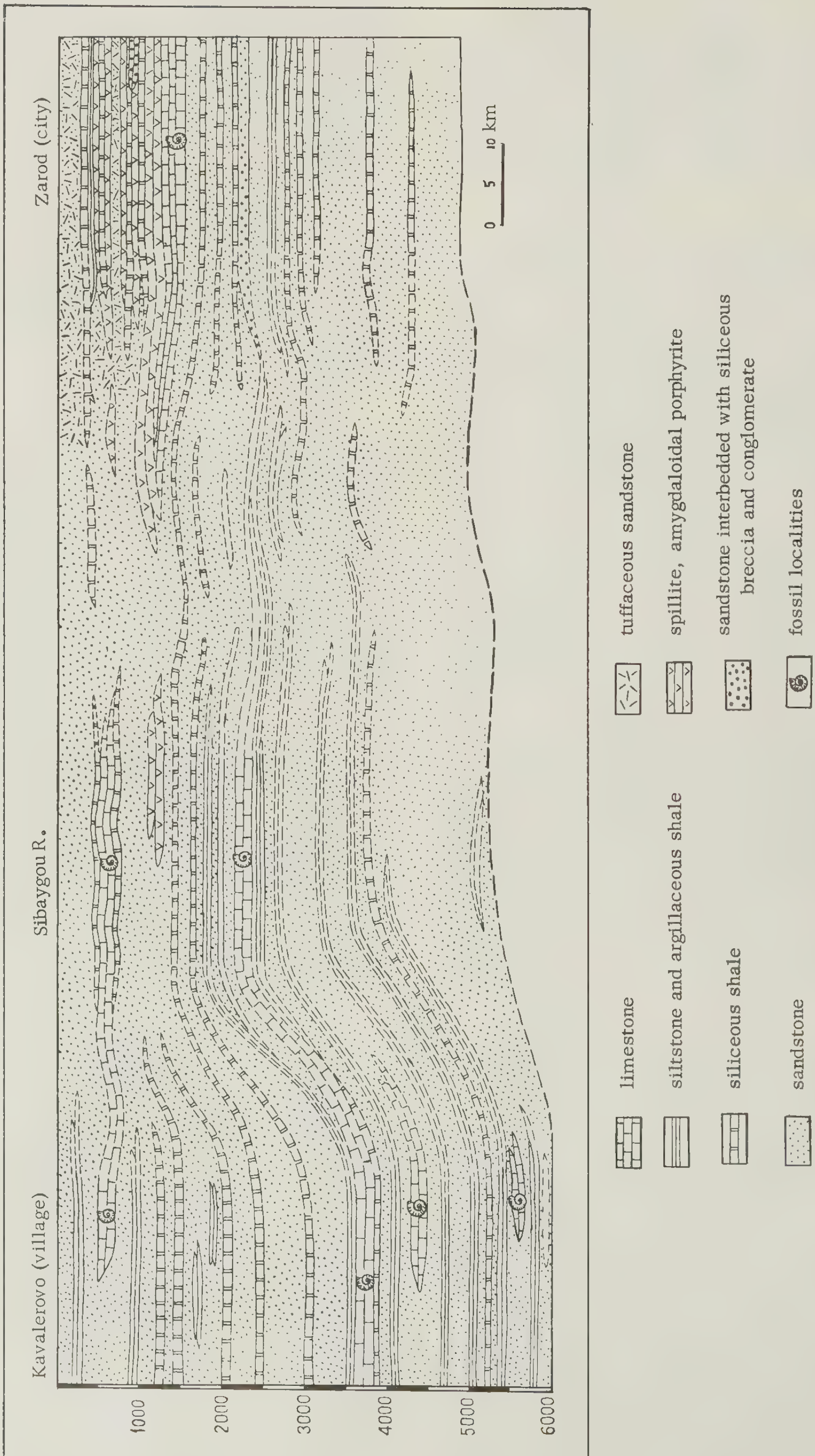
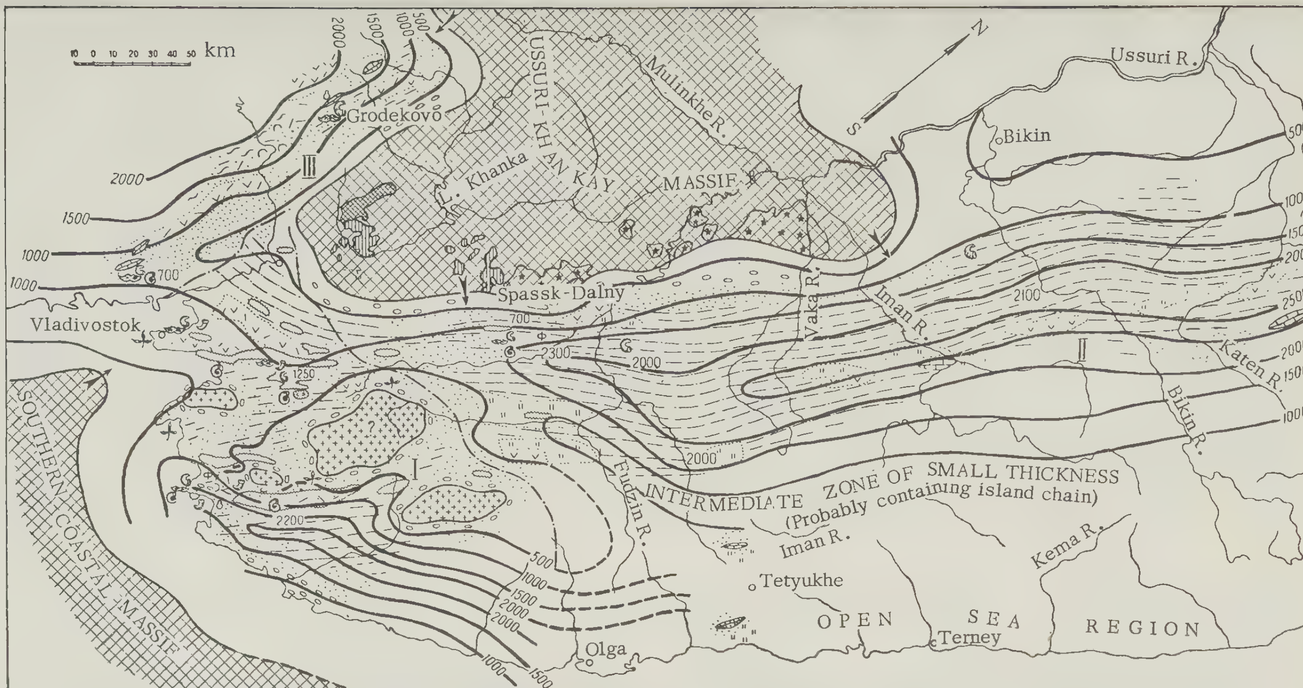


FIGURE 3. Lithologic-stratigraphic profile of upper Paleozoic formations



- ancient land areas, (permanent uplifts, subjects to prolonged degradation)
- Archean gneiss and crystalline schist
- Cambrian-carbonate and terrigenous series
- degradation regions (nonpermanent)
- limestone
- dolomitized limestone
- sandstone
- interbedded sandstone and siltstone
- siltstone and argillite
- siliceous shale, jasper
- conglomerate
- tuffite, tuffaceous sandstone, and shale
- pelitic- and aleuritic-carbonaceous tuff and tuffaceous
- tuff and tuffaceous lava of intermediate and acidic composition
- spillite, diabase porphyrite, and, rarely diabase (in the region of underwater vulcanism
- porphyrite (plagioclase, augite, and others, quartz porphyry, felsite, and their tuffs (in regions of terrigenous vulcanism)
- coal
- glauconite
- flysch-like series
- Kataziatskaya-type flora
- massive brachiopod accumulations (Spirifer rajah and others)
- massive brachiopod accumulations (Lyttonia Waag., Richthofenia Waag.
- massive brachiopod accumulation (Productus kristofovichi Frus and others)
- massive foraminifer accumulation including: Misellina ex gr. lepida, and Colaniella parva and Codonofusinella
- equal thickness lines Ed.: isopachs (actual and apparent)
- structural-facies zone borders
- borders indicating distribution of lithologic complexes
- reefs (supposed)
- principal direction of clastic-sediment transportation
- upper Paleozoic weathered zone.

FIGURE 4. Paleogeographic scheme of the Sikhote-Alin region during the upper Permian

I. Southern coastal region: region of downwarping and marine-sedimentary deposition, accompanied by widespread development of conglomerate and reefs; II. Central Sikhote-Alin zone: area of thick marine sediments (sandy, silty, and siliceous formations predominate), and widely distributed underwater volcanic formations; III. Grodekovsk zone: region of differential uplift and subsidence of small amplitude, carbonate-sandstone in marine troughs, extrusive rocks on uplifts.

Those numbers not indicating isopachs line denote total formation thickness (m)

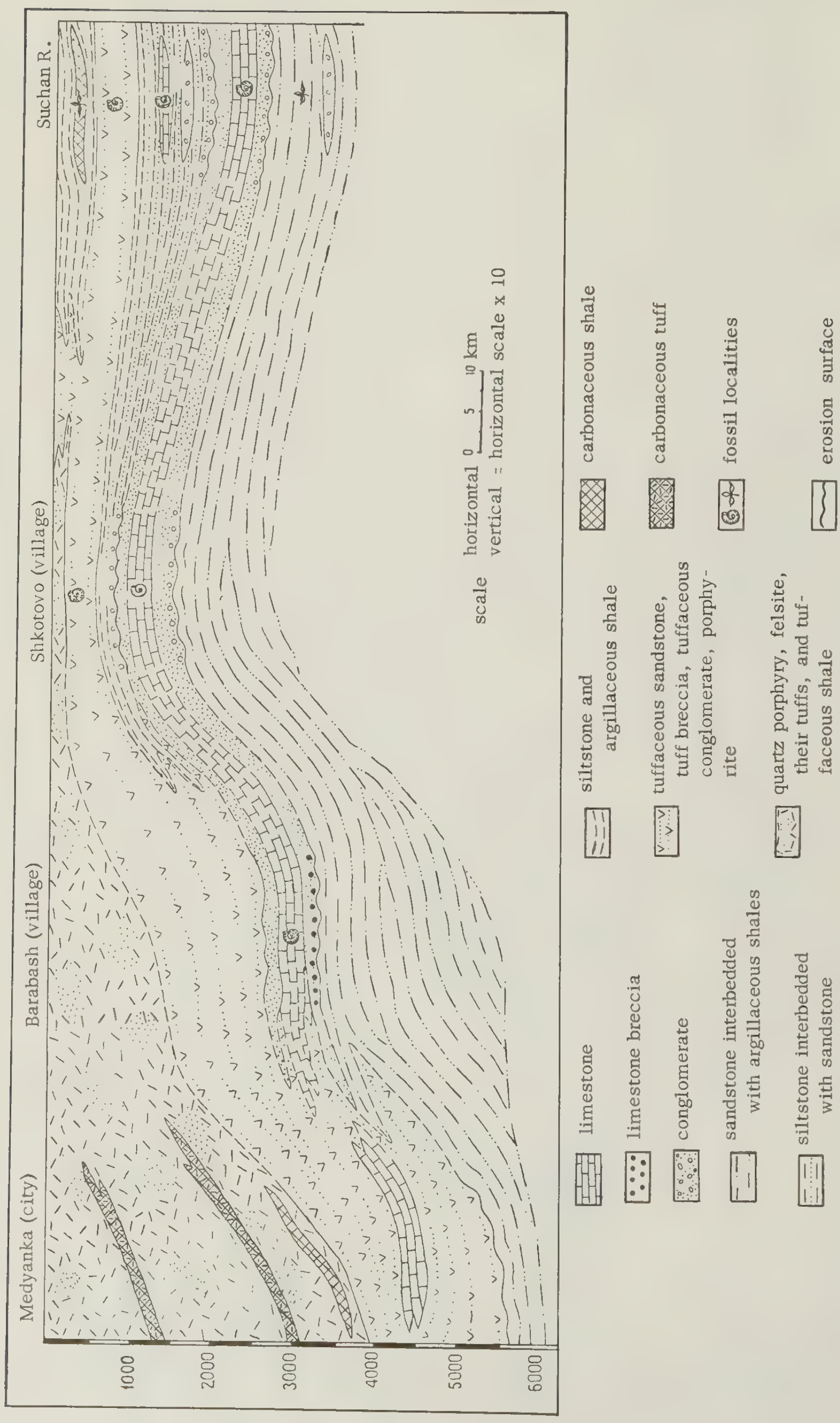


FIGURE 5. Lithologic-stratigraphic profile of upper Paleozoic formations

Permian (fig. 4, see p. 15), as well as the location of ancient volcanic structures, indicates that three facies complexes can be discerned within the Sikhote-Alin region: southern coastal; Grodekovsk; and, central Sikhote-Alin.

The southern-coastal complex, most irregular in composition, is typical of a shallow-water basin environment with complex littoral deposits. From the paleogeographic scheme it is fairly obvious that the coarse-grained clastics of the Obrublennaya mountain region were superseded by sandy siltstone and carbonate rocks toward the Suchana and Maykhe river basins. Locally, carbonaceous-argillaceous shale containing plant remains has been observed (Malaya Sitsa river, Dunay peninsula, Putyatin island, and others). From the lithologic-stratigraphic profile along the Medyanka-Suchana river (fig. 5, see p. 16), it may be noted readily that areal extent and thickness of the volcanics increases from east to west.

Rhythmic sedimentation observed on the Trudnyy peninsula (alternation of siltstone) is related to periodic erosion of alternately coarser and finer material from a gradually rising island massif. The rhythmic nature of these formations indicates, probably, that the Yuzhnoye-Primorsky massif may have been subjected to regular, oscillating movements.

If the upper Permian strata are traced along a vertical plane (from the base), gradual disappearance of the limestone from the section and appearance of clastic rocks, may be observed (Nakhodkinsko-Kaluzinskaya sequence); higher in the section, carbonaceous sediments (Sitsinskaya sequence) occur. The later Permian formations are considerably richer in volcanic material. Cross-bedded sandstone, carbonaceous shale, and conglomerate are characteristic of the upper Permian, indicating a gradual shoaling of the late Permian sea in the southern coastal region. Total thickness of upper Permian formations in the eastern sector of of the southern coastal region (Trudnyy peninsula) is approximately 2,000 m. In the northwest (Shkotovsky region), thickness ranges from 500 to 1,000 m.

The fossils of the upper Permian formations, principally brachiopods, bryozoans, and foraminifers, are abundant and varied; foraminifers are so abundant locally, they may be considered to be rock-forming organisms. A feature typical of the upper Permian fauna is development of the highly specialized sessile brachiopod groups, Lyttonia and Richthofenia, which were adapted to mobile waters. Fossil distribution as noted some time ago by Maslennikov (1952), is closely related to formation lithology. Obviously, the productids and spirifers lived at relatively shallow depths, on slightly elevated sections of the sea bottom, in sands, and at considerable distances from each others; the gastropods and bryozoans lived in mud. Brachiopods and foraminifers predominate in limestones formed farther from shore.

Limestone deposits, possibly representing former underwater banks located along the continental shelf, stretch for distances of 20 to 60 km. Typically they contain massive accumulations of foraminifers (primarily, the Misellina group), crinoids, brachiopods, bryozoans, and corals. Further detailed work is necessary to determine whether the limestone contains reefs.

During the late Permian, the paleogeographic environment of the Grodekovsk zone had certain distinctive features: Volcanic activity resulting in the deposition of acidic and basic lava and ejecta, was less common in this area than in southeastern sections of the southern coastal region. At the beginning of the upper Permian, marine sediments were deposited. The limestone contains abundant brachiopods, bryozoans, corals, and foraminifers, similar to the upper Permian fauna of the southern coastal region. Later, marine sediments gave place gradually to material of volcanic origin: e. g., tuffaceous shale, tuffaceous sandstone and carbonaceous tuff.

Deposition of the central Sikhote-Alin type occurred in a marine basin east of the Ussuri-Khankaysky massif. Very coarse-grained clastic sediment (conglomerate and gravelly sandstone) accumulated in the littoral zone of this basins; farther east, finer deposits were formed (sandstone and some limestone). Widespread occurrence of chert and tuffaceous rocks in the upper Permian of the central Sikhote-Alin zone suggests extensive vulcanism during the period.

Toward the end of the Permian, predominance of uplifts in the southern and southwestern Primorye is not very clearly indicated in the central Sikhote-Alin zone; here, the conglomerate succeeded sandy-argillaceous and siliceous formations higher in the section. East of the Daubikhe river, a flysch-like series was developed. Apparently, rapidly growing uplifts provided sandy-argillaceous material of considerable volume; these sediments were deposited rhythmically.

CONCLUSIONS

This brief stratigraphic and paleogeographic description permits formulation of several questions, whose answers require specialized investigations.

A siliceous-volcanic formation, potential source for manganese ores of the Vandansky type is widely developed in the middle and upper Carboniferous and in the Permian of the central Sikhote-Alin and Olga-Tetyukhinsk zones (Kropotkin, 1952). Distribution of this

formation is shown on the paleogeographic map.

In the upper Paleozoic carbonate series, skarn iron ores may occur, particularly in anticlinal structures; in addition, this series may contain tin and associated lead-zinc deposits (Olga-Tetyukhinsk zone). Moreover, the upper Paleozoic formations may contain polymetallic deposits.

Special investigations should be conducted to determine the possibility of bauxite deposits. The inner regions of the Sikhote-Alin geosyncline are favorable prospecting areas for bauxite (Ussuri-Khankaysky and Yuzhnoye-Primorsky massifs).

Prospects for upper Paleozoic coal deposits are very limited: The Sikhote-Alin region north of the southern coastal zone has been subjected to prolonged marine inundation along a relatively stable shoreline; thus, this region cannot be considered favorable for coal. In the southern coastal region, conditions for accumulation of coal-forming material were more favorable; even there, however, industrial coal deposits could not have formed.

The stratigraphy proposed for the Carboniferous and Permian formations of Sikhote-Alin still presents several unsolved problems: 1) the boundary between the Carboniferous and the Permian is still undefined; 2) the stratigraphic position of upper Permian continental formations requires further explanation; 3) correlation of the central Sikhote-Alin sections is not complete (e. g., correlation of stratigraphic columns having lithologically similar accumulations of siliceous and extrusive rocks). Investigations employing paleontologic, paleobotanic, and lithologic-petrographic methods are necessary for a solution to these problems.

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MINERALOGY OF SIBERIAN KIMBERLITES [1]

by

G. I. Smirnov

• *translated by Royer & Roger, Inc.* •

ABSTRACT

Siberian kimberlite minerals are classified according to their occurrence and origin as: 1) Kimberlite minerals - associated directly with kimberlite formation (pyrope, ilmenite, olivine, magnetite, diopside and chrome-diopside, chrome-spinel, perovskite, micas, and enstatite and hypersthene); 2) Xenolithic minerals - either directly related to kimberlites by chemical composition - or in association with this group, but compositionally unrelated to the kimberlites; and, 3) Secondary minerals - formed in secondary alteration of kimberlite principally by serpentinization and carbonitization, and, to a lesser degree, by silicification, chloritization, and pyritization processes. Mineral specimens under investigation were taken at depths not exceeding 3 to 4 meters; thus, they indicate known composition for only the uppermost portion of the kimberlite pipes. Basically Siberian and South African kimberlites are similar: between the two areas, there is little variation in mineral composition; quantitative differences exist locally, governed by conditions surrounding mineral formation. Mg content in pyrope, olivine, diopside, ilmenite, etc. is high in both kimberlites. In addition, both areas have undergone extensive secondary alteration by comparable processes. --D.D. Fisher.

The following information on the mineralogy of Siberian kimberlite is based on results of preliminary study of crushed test samples, of concentrates produced by beneficiation, and of granular material obtained from prospecting work in "Mir" and "Zarnitsa" kimberlite pipes. The specimens investigated were obtained from depths no greater than 3 or 4 meters; and thus, represent only the uppermost levels, including eluvia, of kimberlite pipes. In addition a partial study was made of specimens from the eluvia of "Zagadochnaya" and "Dalnyaya" kimberlite pipes.

A brief account on the mineralogy of "Zarnitsa" kimberlite pipe is presented in a paper by N. N. Sarsadskyye and L. A. Popugayeva (1955).

Three mineral groupings were found: 1) minerals associated directly with kimberlite formation (e.g., olivine, garnet, ilmenite, chrome-spinel, etc.); 2) minerals contained in numberous xenoliths, both those related by mineral composition to kimberlite, and those which differ (eclogite-like inclusions, inclusions of schist, trap-rock, limestone, etc); 3) minerals formed through subsequent alteration of kimberlite: these are represented chiefly by serpentine, carbonate minerals, chlorite and iron hydroxides; and, more rarely, by barite, celestite and pyrite.

Table 1 lists minerals found in Siberian kimberlite.

TABLE 1. Mineral composition of Siberian kimberlite[2]

Primary kimberlite minerals	Xenolithic minerals	Secondary minerals
diamond	almandine	actinolite
diopside	apatite	barite
ilmenite	biotite	biotite
magnetite	hypersthene	vermiculite
olivine	diopside	hydromica
perovskite	disthene	hypersthene
pyrope	dolomite	dolomite
phlogopite	calcite	calcite
chrome-spinel	quartz	calciostrontianite
enstatite	magnetite	quartz
	plagioclase	leucoxene
	hornblende	limonite
		magnetite
	rutile	perovskite
	sphene	pyrite
	tourmaline	plagioclase
	zircon	serpentine
	spinel	phlogopite
		chalcedony
		chlorite

Although mineral composition of kimberlite is fundamentally constant, significant variations in relative amounts of various individual minerals have been noted in different deposits. Thus, for example, high ilmenite content is found in "Zarnitsa" kimberlite, lower content

[1]Translated from K mineralogii sibirskikh kimberlitov: Trudy Yakutskogo Filiala AN SSSR, no. 4, p. 47-74, 1959.

[2]Minerals are listed in order (according to Cyrillic alphabet). Grossularite-garnet found in eluvium of "Mir" pipe is not included here, because there is no doubt of its mechanical transportation from skarn formations.

in "Mir" pipe, and, in the eluvium of "Zagodochnaya" pipe, very low ilmenite content. On the other hand, chrome-diopside is present in large quantities in "Zagodochnaya" eluvium, in noticeable amounts in "Dalnyaya" pipe, but, completely absent in "Mir" and "Zarnitsa" pipes.

There is associated with other mineralogic variations within kimberlite, in certain deposits, a relatively large amount of unaltered olivine (in the eluvium of "Dalnyaya" pipe, for example, where olivine commonly amounts to approximately 40 - 50 percent electromagnetic fraction of the concentrate). In most deposits investigated, however, such as "Mir" and "Zarnitsa", olivine is replaced almost entirely by serpentine, and, rarely unaltered.

Table 2 gives some examples of different minerals in relative amounts for a number of kimberlite pipes.

In descriptions given below of minerals whose occurrence has been established in kimberlite pipes, particular attention is given to pyrope and ilmenite, the basic accessories of diamond. Diamond, not of primary concern in these investigations, was omitted.

Minerals are classified according to the three groupings cited above. However, when a given mineral is formed under both magmatic and hypergene conditions (magnetite, mica, etc), it is described under one classification only, but with indication as to origin.

KIMBERLITE MINERALS

Pyrope: As can be seen from Table 2, this mineral is widespread in all kimberlite bodies under consideration.

Pyrope commonly occurs as discrete grains disseminated through the kimberlite; under the microscope, they are easily distinguishable from their background of dark gray or gray-green serpentinized kimberlite, by their characteristic reddish color. Moreover, in eclogite inclusions, there are grains of garnet occasionally with almandine, in which pyrope component predominates, as described below.

Pyrope is represented generally by somewhat flattened, rounded grains (fig. 1); also common are angular fragments. The grains usually have a rough surface with numerous tiny fractures; these contain secondary minerals that give pyrope a dirty, grayish-red color.

Grain size in pyrope varies from 0.1 to 1.0 centimeters (cm) in diameter; average, and mean, grain size is from 2 to 3 millimeters (mm). Surrounding pyrope grains is a grayish-white or greenish-black kelephitic rim (formed through action by residual magmatic solutions on the complex composition of garnet (see

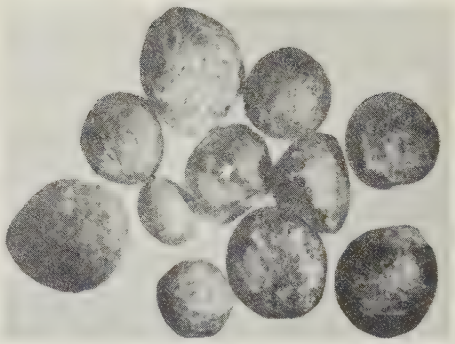

FIGURE 1. Pyrope grains from "Zarnitsa" kimberlite pipe. x 4.2

tables 5 and 6), the pyrope component predominant) occasionally displaying distinct, radial structure (fig. 2). These rims vary greatly in thickness, from almost nothing to 1.5 - 2 mm. According to determinations by M. Yu. Fishkin (Professor of Mineralogy in the Lvov State University), kelephitic rims are composed of the following minerals: 1) bright green chlorite with N_m = 1.622 and N_p = 1.609, with blue anomalous interference colors; 2) biotite, pleochroic in light-brown colors; N_g - N_m = 1.630, N_p = 1.609; 3) calcite, with N_o = 1.656; and, in some grains, dolomite with N_o = 1.682.

In association with chlorite there is generally a fibrous amphibole, evidently actinolite, having N_g = 1.643 and N_p = 1.620; and, a large negative 2V angle.

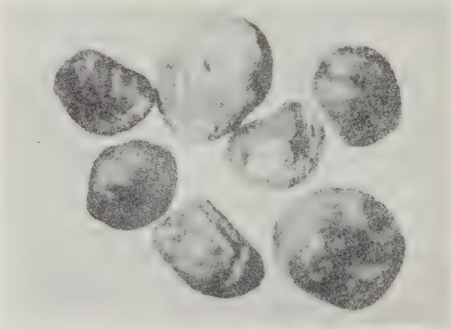

FIGURE 2. Pyrope grains exhibiting kelephytic rims. "Zagadochnaya" pipe. x 3.6

Kelephitic rims around pyrope are sometimes white or grayish-white and are composed of micaceous, fine aggregate with N_g = 1.532; this is evidently hydromica. Kelephitic rims also contain single grains of tabular hypersthene, pleochroic in greenish-yellow, with refractive indices N_g = 1.711 and N_p = 1.698; as well as

TABLE 2. Relative quantities of Siberian kimberlite minerals

Deposit	Primary Kimberlite and Xenolithic Minerals		Secondary Minerals	
	Frequent	Rare	Frequent	Rare
"Zarnitsa"	ilmenite pyrope	almandine diopside	serpentine calcite	chlorite celestite
"Mir"	ilmenite pyrope magnetite	biotite olivine zircon chrome-spinel apatite quartz almandine diopside chrome-diposide chrome-spinel zircon quartz apatite disthene rutile enstatite	limonite quartz chalcedony serpentine chlorite magnetite calcite dolomite limonite quartz	dolomite hypersthene feldspars
"Zagadochnaya"	pyrope chrome-diopside almandine magnetite	ilmenite diopside phlogopite hornblende biotite chrome-spinel apatite disthene spinel rutile sphene zircon	serpentine calcite dolomite magnetite quartz limonite	barite celestite chlorite
"Dalnyaya"	ilmenite pyrope olivine magnetite chrome-diopside	diopside hornblende biotite chrome-spinel almandine hypersthene spinel disthene zircon	serpentine calcite dolomite magnetite quartz limonite	perovskite leucoxene pyrite

andesine, with refractive indices $N_g = 1.558$ and $N_p = 1.550$.

Great variety in color has been observed in pyrope: red, lilac, pink, orange, and almost colorless pyrope have been reported. In addition, many, very fine shades form gradual transitions between these principal colors for different varieties of pyrope.

Several pyrope grains were found in "Mir" and "Zarnitsa" pipes; these grains appear to change color under various types of illumination. Change in color with change in illumination has been observed in immersion preparations under the microscope: in natural light pyrope is green; under artificial light, red. Varying absorption for different light wavelengths is similar, in this case, to the same phenomenon in alexandrite; and, evidently, has the same cause.

A. P. Bobriyevich has established the matrix of these pyropes to be extensively altered, serpentinized rock appearing as nodules in kimberlite (of "Mir" pipe). In composition, this rock is the extensive analogue of peridotite.

One definite color characteristically predominates in pyropes from each separate deposit. Thus, for example, red and dark-red pyropes are encountered most frequently in

"Zarnitsa" kimberlite; and, lilac and orange pyropes in "Mir" and "Zagadochnaya" pipes, respectively.

In order to determine the nature of pyrope coloration, L. M. Krasov has investigated specimens from "Zarnitsa" pipe, and has studied their light absorption by pyrope within the visible spectrum as well as relation of light absorption to ionic composition possibly affecting coloration of the mineral.

A UM-2 monochromator was used to study light-absorption curves. The specimen, shaped and polished into a thin plate with parallel surfaces, was placed in front of the entry slot (next to the second lens of a three-lens illumination system); the intensity of light radiation passing through the system was recorded by an FEU-19 photoelectronic intensifier and a self-balancing direct-current amplifier.

Values of K, i.e., magnitude of absorption of coefficient per unit thickness were

$$K = \left(\frac{1}{x}\right)\ln\left(\frac{I_0}{I}\right)$$

calculated for each specimen; values were not computed for dispersion coefficients. The resulting curves appear in figures 3 through 9 inclusive.

The light-absorption curves show two prominent maxima, the regions of 410 - 420 and 560 - 570 mm, respectively. Height of crests

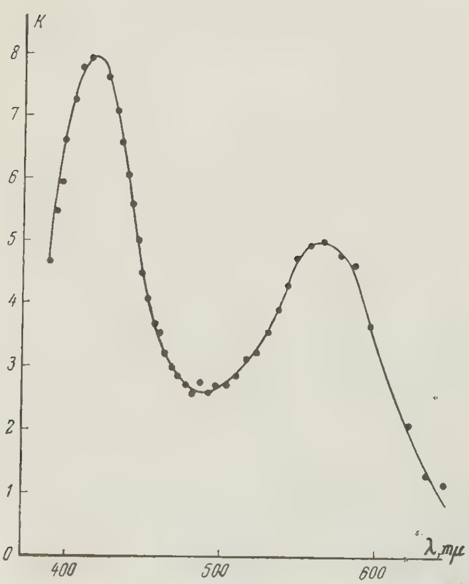

FIGURE 3. Absorption curve of vio[illegible] pyrope. Specimen KP-4c.

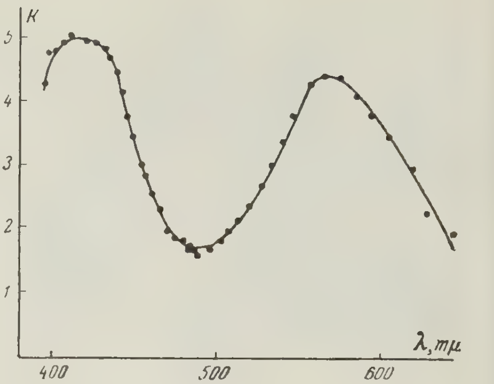

FIGURE 4. Absorption curve of dark violet-red pyrope. Specimen KP-4c.

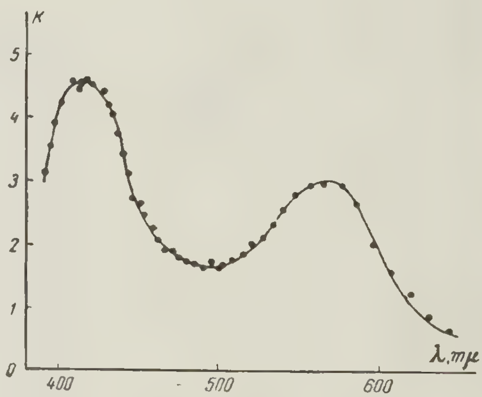

FIGURE 5. Absorption curve for violet-red pyrope. Specimen KP-5d.

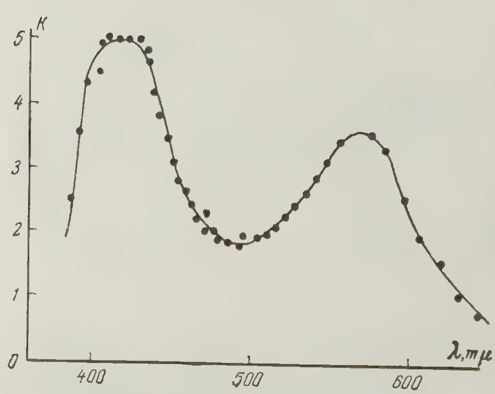

FIGURE 6. Absorption curve for violet-red pyrope. Specimen KP-4a.

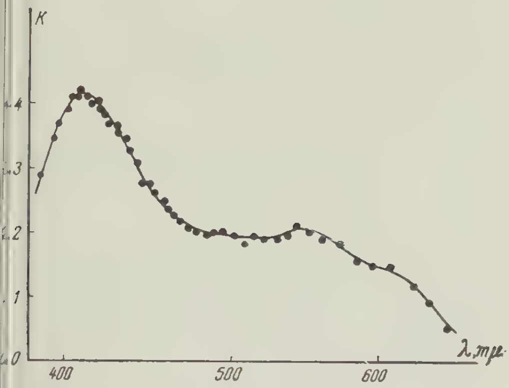

FIGURE 7. Absorption curve for orange pyrope. Specimen KP-7a.

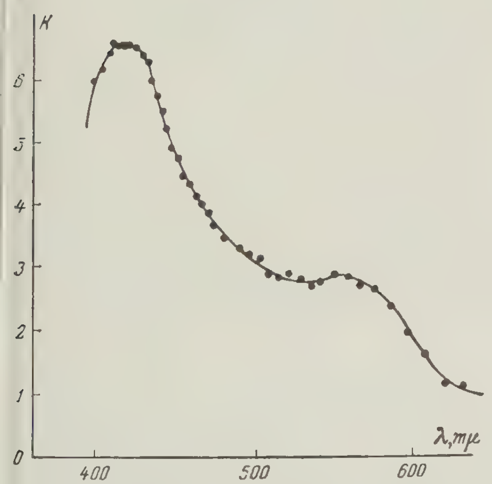

FIGURE 8. Absorption curve for orange pyrope. Specimen KP-7b.

naturally, varies with the color depth [intensity]. In the case of specimens 4, 5, 6, and 7a, the second crest (560-570 mm) on the absorption curve is clearly lower, thus explaining the color difference between these specimens and others.

Comparison of these curves with others reported in the literature (Grum-Grzhimaylo, Klimovskaya, Vinevskiy, 1954; Sobolev, 1949) shows that the second crest (560-570 mm) must be attributed to a Cr^3 ion with six-fold coordination. The first crest (410-420 mm) may be explained by the presence of Fe^3 ions; however, Fe^2 also is present in the garnets considered here (table 5). The known absorption curves for simultaneous action of these cations (Sobolev, 1949) do not correspond to those obtained during this investigation. The first crest, in similar position, is seen on absorption curves for minerals colored by manganese (Grum-Grzhimaylo, Klimovskaya, Vinevskiy, 1954).

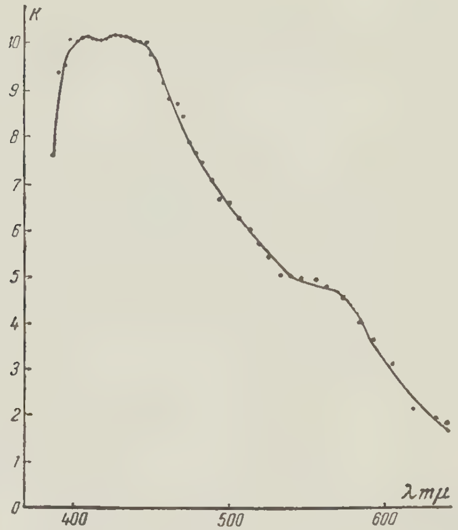

FIGURE 9. Absorption curve for orange pyrope. Specimen KP-4b.

Spectrum analyses were made for Cr, Ti and Mn content in garnet specimens to determine the effect of relative concentration of these elements on absorption-curve shape and, thus, on mineral color. (Because mixtures with graphite were used as standard, determination of exact concentration for elements under consideration is not completely reliable, but sufficient to determine relative changes from specimen to specimen.)

TABLE 3. Results of a quantitative spectrum analysis of pyrope*

Elements	7-a	7-b	5-b	5-d	4-a	4-b	4-c
	orange		violet-red		orange		violet-red
Cr	2.40	2.00	4.00	6.90	4.50	2.40	7.40
Ti	0.63	0.33	0.11	0.22	0.13	0.74	0.12
Mn	0.23	0.13	0.09	0.24	0.08	0.07	0.41

*Yu. V. Dubatovko

Results of these analyses, given in Table 3, show decrease in the second crest on the absorption curve to correspond to decrease in chromium content. In addition, when Ti content is increased, one observes "erosion", so to speak, of the first peak, less sharp in Specimen 4b. The effect of Mn-concentration change on absorption-curve shape has not been determined.

These investigations then have shown the second maximum is definitely resultant from action of Cr ions, and, flattening of the first crest, from an increase in Ti content. The nature of the first crest, however, is not yet clear (i.e., whether it is caused by presence

of Mn, or by action of Fe^3 without the effect of Fe^2). This aspect requires further investigation; studies should be made also of absorption-curve spectra ultraviolet and infrared regions.

The refractive index of pyrope also ranges within wide limits, N = 1.732-1.777. In addition, as can be seen from the data in Table 4, there is a considerable overlapping of refractive indices for the various color varieties of pyrope. Within a single variety, however, increase in refractive index is associated with increase in color density of pyrope.

TABLE 4. Refractive indices for variously colored pyrope*

Pyrope color	Color intensity and refractive color variation	
	light	dark
violet-red	1.744-1.749	1.754-1.777
orange-red	1.744-1.749	1.754-1.759
red-orange	1.749	1.754-1.759
orange	1.744-1.749	1.754-1.759
lilac	1.744-1.749	1.754-1.764
raspberry-pink	1.739-1.749	1.754-1.764
pink	1.738-1.744	1.763
colorless	1.732-1.767	---

*Refractive indices of pyrope were measured in normal light; an error of ± 0.002 was recorded.

Most pyropes have refractive indices ranging from 1.744 to 1.759; those with higher or lower refractive indices are uncommon.

L. M. Leybova has investigated garnet from two eclogite inclusions in kimberlite. In the inclusion having higher garnet content, the garnet was found to be pyrope variety; its refractive index, about 1.767. Four varieties of garnet were found in the second inclusion: three had the composition of pyrope (pale pink, almost colorless, with refractive index (N) somewhat greater than 1.738; bright lilac, somewhat higher than 1.754; bright orange, a little more than 1.754). A bright yellow garnet was determined to be almandine; its refractive index was considerably greater than 1.780.

Some pyrope grains contain inclusions of other minerals. Some of these inclusions are idiomorphic, chrome-spinel grains with well-developed octahedral faces; others are needle-like or tabular rutile. Fairly large emerald-green, chrome-diopside inclusions (as much as 1.5 mm in diameter) occur in some grains.

Table 5b gives chemical composition and some physical properties (pyropes were chosen for chemical analysis both by color and by refractive index. Refractive indices were determined by T. G. Petrov, of the Chair of Crystallography, Leningrad State University; chemical analyses were made in the laboratory of the All-Union Geological Institute) of the pyropes from the "Zarnitsa" pipe. For purposes of comparison, Table 6 shows the results of chemical analyses of garnet from the kimberlite of South Africa and the crystalline rocks of the Aldan shield.

The results of the chemical analyses of garnet are given in the form of crystallochemical formulas (see table 5a).

For the sake of more graphic comparison, Tables 7 and 8 recapitulate chemical composition of garnet; based on crystallochemical formulas, it is presented in terms of relative composition for the individual garnet components in each specimen.

Table 7 shows that, in garnet under investigation, the pyrope component ranges from 69 to 76.2 percent; thus this garnet legitimately may be called pyrope. Almandine, second in abundance, varies in amount from 10 to 18.6 percent. An important feature of pyrope is the constant presence of chromium; moreover, it has been established that chromium content in red pyrope varieties is much greater than in orange (Table 5). In addition, pyrope under consideration here, like that from South African kimberlite, contains small amounts of andradite (from 0.6 to 10 percent); grossularite (from 2 to 5 percent) occurs in certain others. Most pyrope also contains spessartite in very small quantities (from 3 to 0.7 percent).

Thus, pyrope from Siberian kimberlite is similar to that from South African kimberlite in chemical composition as well as in relative content of chief garnet components; it differs sharply from garnet of ancient (Archean) crystalline schist (comprising mountain structures which surround the Siberian platform). Table 8 shows that almandine content greatly exceeds that of pyrope in garnet from Aldan shield crystalline rocks; in this garnet, chromium is either absent or present in insignificant amounts.

It has been noted above, that ilmenite is widely distributed in most kimberlite deposits; it occurs in insignificant quantities only in "Zagadochnaya" pipe.

Ilmenite grains vary in size as much as those of pyrope, though it must be stressed that, particularly in the "Zarnitsa" pipe, this mineral occurs, on the average, in rather large grains: diameters of individual ilmenite grains commonly exceed 10 mm. For the very largest discrete particles of ilmenite, called nodules rather than grains, cross section is as large as 2 - 3 cm.

Ilmenite generally occurs as angular fragments (fig. 10). Ilmenite grain surfaces usually are covered by a thin gray layer of leucoxene. In places, this leucoxene fringe is as thick as

TABLE 5a. Crystallochemical formulas for garnet

1. $(\mathrm{Mg}_{2.16}\,\mathrm{Fe}^{\cdot\cdot}_{0.34}\,\mathrm{Mn}_{0.01}\,\mathrm{Ca}_{0.36})_{2.87}\,(\mathrm{Al}_{1.66}\,\mathrm{Fe}^{\cdot\cdot\cdot}_{0.12}\,\mathrm{Cr}_{0.14}\,\mathrm{Ti}_{0.02})_{1.96}\,[\mathrm{Si}_3\mathrm{O}_{12}] + 0.09\,\mathrm{SiO}_2$
2. $(\mathrm{Mg}_{2.26}\,\mathrm{Fe}^{\cdot\cdot}_{0.43}\,\mathrm{Mn}_{0.01}\,\mathrm{Ca}_{0.40})_{3.10}\,(\mathrm{Al}_{1.60}\,\mathrm{Fe}^{\cdot\cdot\cdot}_{0.03}\,\mathrm{Cr}_{0.22}\,\mathrm{Ti}_{0.01})_{1.86}\,[\mathrm{Si}_3\mathrm{O}_{12}] + 0.03\,\mathrm{SiO}_2$
3. $(\mathrm{Mg}_{2.23}\,\mathrm{Fe}^{\cdot\cdot}_{0.35}\,\mathrm{Mn}_{0.02}\,\mathrm{Ca}_{0.51})_{3.11}\,(\mathrm{Al}_{1.80}\,\mathrm{Fe}^{\cdot\cdot\cdot}_{0.12}\,\mathrm{Cr}_{0.22})_{2.14}\,[\mathrm{Si}_{2.81}\,\mathrm{Ti}_{0.02}\mathrm{O}_{12}]$
4. $(\mathrm{Mg}_{2.24}\,\mathrm{Fe}^{\cdot\cdot}_{0.43}\,\mathrm{Mn}_{0.01}\,\mathrm{Ca}_{0.38})_{3.06}\,(\mathrm{Al}_{1.73}\,\mathrm{Fe}^{\cdot\cdot\cdot}_{0.08}\,\mathrm{Cr}_{0.10}\,\mathrm{Ti}_{0.02})_{1.93}\,[\mathrm{Si}_3\mathrm{O}_{12}] + 0.01\,\mathrm{SiO}_2$
5. $(\mathrm{Mg}_{2.06}\,\mathrm{Fe}^{\cdot\cdot}_{0.46}\,\mathrm{Mn}_{0.01}\,\mathrm{Ca}_{0.53})_{3.06}\,(\mathrm{Al}_{1.64}\,\mathrm{Fe}^{\cdot\cdot\cdot}_{0.18}\,\mathrm{Cr}_{0.08}\,\mathrm{Ti}_{0.04})_{1.94}\,[\mathrm{Si}_3\mathrm{O}_{12}]$
6. $(\mathrm{Mg}_{2.17}\,\mathrm{Fe}^{\cdot\cdot}_{0.49}\,\mathrm{Mn}_{0.02}\,\mathrm{Ca}_{0.38})_{3.06}\,(\mathrm{Al}_{1.64}\,\mathrm{Fe}^{\cdot\cdot\cdot}_{0.16}\,\mathrm{Cr}_{0.03}\,\mathrm{Ti}_{0.05})_{1.88}\,[\mathrm{Si}_3\mathrm{O}_{12}] + 0.04\,\mathrm{SiO}_2$
7. $(\mathrm{Mg}_{2.08}\,\mathrm{Fe}^{\cdot\cdot}_{0.56}\,\mathrm{Ca}_{0.37})_{3.01}\,(\mathrm{Al}_{1.84}\,\mathrm{Fe}^{\cdot\cdot\cdot}_{0.12}\,\mathrm{Cr}_{0.02})_{1.98}\,[\mathrm{Si}_{2.97}\,\mathrm{Ti}_{0.03}\mathrm{O}_{12}]$
8. $(\mathrm{Mg}_{2.27}\,\mathrm{Fe}^{\cdot\cdot}_{0.40}\,\mathrm{Ca}_{0.31})_{2.98}\,(\mathrm{Al}_{1.88}\,\mathrm{Fe}^{\cdot\cdot\cdot}_{0.05}\,\mathrm{Cr}_{0.03}\,\mathrm{Ti}_{0.02})_{1.98}\,[\mathrm{Si}_3\mathrm{O}_{12}] + 0.01\,\mathrm{SiO}_2$
9. $(\mathrm{Mg}_{1.74}\,\mathrm{Fe}^{\cdot\cdot}_{0.73}\,\mathrm{Mn}_{0.02}\,\mathrm{Ca}_{0.40})_{2.89}\,(\mathrm{Al}_{1.93}\,\mathrm{Cr}_{0.17})_{2.10}\,[\mathrm{Si}_{2.98}\mathrm{O}_{12}]$
10. $(\mathrm{Mg}_{1.79}\,\mathrm{Fe}^{\cdot\cdot}_{0.81}\,\mathrm{Ca}_{0.37})_{2.97}\,(\mathrm{Al}_{1.96}\,\mathrm{Cr}_{0.08})_{2.04}\,[\mathrm{Si}_{2.99}\mathrm{O}_{12}]$
11. $(\mathrm{Mg}_{2.06}\,\mathrm{Fe}^{\cdot\cdot}_{0.55}\,\mathrm{Ca}_{0.38}\,\mathrm{Mn}_{0.02})_{3.01}\,(\mathrm{Al}_{1.86}\,\mathrm{Fe}^{\cdot\cdot\cdot}_{0.09}\,\mathrm{Cr}_{0.09})_{2.10}\,[\mathrm{Si}_{2.96}\mathrm{O}_{12}]$
12. $(\mathrm{Mg}_{2.14}\,\mathrm{Fe}^{\cdot\cdot}_{0.47}\,\mathrm{Mn}_{0.02}\,\mathrm{Ca}_{0.40})_{3.03}\,(\mathrm{Al}_{1.83}\,\mathrm{Fe}^{\cdot\cdot\cdot}_{0.21}\,\mathrm{Cr}_{0.06})_{2.10}\,[\mathrm{Si}_{2.98}\mathrm{O}_{12}]$
13. $(\mathrm{Mg}_{0.89}\,\mathrm{Fe}^{\cdot\cdot}_{1.73}\,\mathrm{Mn}_{0.05}\,\mathrm{Ca}_{0.14})_{2.81}\,(\mathrm{Al}_{2.00}\,\mathrm{Fe}^{\cdot\cdot\cdot}_{0.08})_{2.08}\,[\mathrm{Si}_{3.03}\mathrm{O}_{12}]$
14. $(\mathrm{Mg}_{0.47}\,\mathrm{Fe}^{\cdot\cdot}_{1.90}\,\mathrm{Mn}_{0.12}\,\mathrm{Ca}_{0.30})_{2.79}\,(\mathrm{Al}_{2.00}\,\mathrm{Fe}^{\cdot\cdot\cdot}_{0.05})_{2.05}\,[\mathrm{Si}_{3.07}\mathrm{O}_{12}]$
15. $(\mathrm{Mg}_{0.78}\,\mathrm{Fe}^{\cdot\cdot}_{1.96}\,\mathrm{Mn}_{0.06}\,\mathrm{Ca}_{0.05})_{2.85}\,(\mathrm{Al}_{2.10}\,\mathrm{Fe}^{\cdot\cdot\cdot}_{0.08})_{2.18}\,[\mathrm{Si}_{2.95}\mathrm{O}_{12}]$
16. $(\mathrm{Mg}_{0.86}\,\mathrm{Fe}^{\cdot\cdot}_{1.59}\,\mathrm{Mn}_{0.09}\,\mathrm{Ca}_{0.15})_{2.69}\,(\mathrm{Al}_{2.03}\,\mathrm{F}^{\cdot\cdot\cdot}_{0.17})_{2.20}\,[\mathrm{Si}_{3.01}\mathrm{O}_{12}]$

TABLE 5b. Chemical composition and certain physical properties of pyrope from "Zarnitsa" deposit

Specimen no.	1	2	3	4	5	6	7	8
Pyrope color	Violet red[1]	Dark violet red[2]	Dark violet red[1]	Orange red[2]	Orange red[3]	Red orange[1]	Orange[4]	Raspberry pink[4]
Components								
SiO_2	43.26	41.98	38.80	41.70	41.20	41.93	41.20	42.83
TiO_2	0.50	0.32	0.38	0.45	0.76	1.04	0.60	0.40
Al_2O_3	19.72	18.91	21.00	20.42	19.24	19.20	21.75	22.30
Fe_2O_3	2.24	0.62	2.25	1.42	3.22	3.00	2.21	1.03
Cr_2O_3	2.70	4.02	3.82	1.91	1.56	0.65	0.33	0.70
FeO	5.61	7.18	5.70	7.27	7.40	8.08	9.31	6.72
MnO	0.20	0.24	0.44	0.21	0.22	0.33	—	—
MgO	20.27	20.98	20.60	20.86	18.70	20.03	19.32	21.30
CaO	4.73	5.21	6.72	5.94	6.83	4.93	4.74	4.06
H_2O	—	—	—	—	—	—	0.10	0.10
Others	1.16	1.00	0.66	1.19	1.12	1.23	1.00	0.95
Total	100.39	100.46	100.37	100.38	100.25	100.42	100.56	100.39
Refractive index	1.749	1.754	1.759	1.744	1.749	1.754	1.754	1.744
Specific gravity . .	3.68	3.75	3.72	3.73	3.65	3.77	3.74	3.76
	Not determined	11.534	11.522	11.509	11.527	11.532	Not determined	

[1]V. Kovyzina, [2]O. Boyarshinova, [3]K. A. Baklanova, [4]M. Stukalova

TABLE 6. Chemical compositions of garnet from South African kimberlite and Aldan shield crystalline rocks

Specimen no.	[1]9	[1]10	[1]11	[1]12	[2]13	[2]14	[3]15	[3]16
Deposit	Kimberly	Kimberly	Mukerob	Mukerob	Archean gneiss of Aldan shield			
Components								
SiO_2	41.34	40.90	40.89	40.47	39.42	38.98	37.84	39.04
TiO_2	—	—	—	—	—	traces	—	—
Al_2O_3	22.75	22.81	21.84	21.56	22.00	21.52	22.82	22.41
Fe_2O_3	—	—	1.87	3.83	1.50	0.91	1.31	2.92
Cr_2O_3	2.96	1.48	1.79	1.15	—	—	—	—
FeO	12.12	13.34	9.06	7.84	27.00	26.68	30.17	24.65
MnO	0.36	—	0.30	0.27	0.78	1.80	0.93	1.37
MgO	16.20	16.43	19.17	19.92	7.95	3.99	6.70	7.49
CaO	5.17	4.70	4.93	5.09	1.70	3.57	0.60	1.87
N_2O	—	0.38	—	—	—	—	—	—
Others	—	—	—	—	—	—	—	0.38
Total . . .	100.90	100.04	99.85	100.13	100.35	99.45	100.37	100.13
Color . . .	Deep red	Hyacinth red	Blood red	Brown yellow	—	—	—	—
Specific gravity	—	—	3.78	3.737	—	—	—	—

[1]R. A. Wagner [2]Ye. N. Laurenko [3]M. Ya. Apostolova

TABLE 7. Content of individual garnet components in pyrope from Siberian kimberlite, "Zarnitsa" deposit

Components	Specimen no. *							
	1	2	3	4	5	6	7	8
Pyrope	75.3	72,9	71.7	73.2	70.8	70.9	69.1	76.2
Almandine	10.0	12.9	10.8	14.1	13.4	13.1	18.6	13.4
Spessartite	0.3	0.3	0.7	0.3	0.3	0.3	—	—
Grossularite	—		—	2.0	—	—	5.2	5.4
Andradite	4.3	0.6	5.1	4.1	6.9	8.1	6.1	2.5
Uvarovite	7.2	11.8	11.3	5.2	4.1	1.6	1.0	1.5
Skiagite	1.9	1.0	0.4	—	2.4	0.3	—	—
Ca-Ti-garnet	1.0	0.5	—	1.1	2.1	2.7	—	1.0
Total	100 0	100.0	100.0	100.0	100.0	97.0	100.0	100.0

* Specimens are numbered as in Table 5b.

TABLE 8. Content of individual components in garnet from various sources

Components			Specimen no. *					
	9	10	11	12	13	14	15	16
Pyrope	60.2	60.25	68.4	70.6	31.6	16.8	27.3	31.9
Almandine	25.25	27.25	18.3	15.5	61.6	68.1	66.9	59.3
Spessartite	0.7	—	0.7	0.7	1.8	4.3	2.1	1.1
Grossularite	5.75	8.6	3.8	0.35	0.7	8.3	—	—
Andradite	—	—	4.4	10.0	4.3	2.5	1.7	5.5
Uvarovite	8.1	3.9	4.4	2.85	—	—	—	—
Skiagite	—	—	—	—	—	—	2.0	-
Ca-Ti-garnet	—	—	—	—	—	—	—	—
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	97.8

* Specimens are numbered as in Table 6.

1 - 1.5 mm. Ilmenite fracture surfaces, resinous black, exhibit metallic luster.

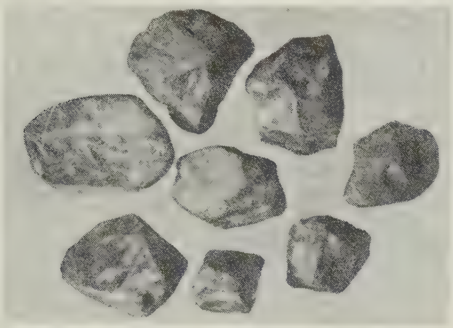

FIGURE 10. Ilmenite grains from "Zarnitsa" kimberlite pipe. x 2.9

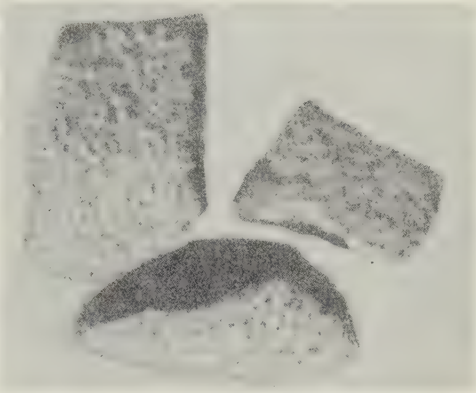

FIGURE 11. Perovskite crystal growth on ilmenite grains. x 13.5

Accretions of tiny perovskite crystals (fig. 11) develop on some ilmenite grains. In thin section, it can be seen that perovskite develops both on the edges of allotriomorphic ilmenite grains and along fractures within ilmenite; this observation testifies to secondary origin of perovskite.

Table 9 shows chemical composition of ilmenite from Siberian kimberlite. For comparison, the table also shows chemical compositions of ilmenite from certain South African kimberlite deposits, as well as two analyses of ilmenite from other, non-kimberlite origin. The table indicates that ilmenite from Siberian kimberlite has considerable magnesium-oxide content; in this respect it resembles ilmenite from South African kimberlite, but differs sharply from ilmenite in basic rocks of other origins (specimens 7 and 8). It has been suggested that Specimen 8, ilmenite from ancient gravel on the watershed between Tyung and Markha rivers, is associated with traprock. This difference appears even more clearly in Table 10, a recapitulation of chemical analyses of ilmenite in terms of content of individual mineral components. According to this table, ilmenite from kimberlite deposits is about one third or more geikielite; whereas, in ilmenite associated with gabbroic rocks, geikielite content does not exceed 9 percent; thus, this ilmenite approaches crichtonite in composition.

TABLE 9. Chemical compositions of ilmenite from various deposits

Components	Specimen no. and deposit							
	1	2	3	4	5	6	7	8
	"Zarnitsa"[1]	"Mir"[1]	Monastery Mine[2]	Kimberly Mine[3]	Mukerob Mine[3]	Frank Smith Mine[2]	Gabbroic massif, Eastern Greenland[4]	Ancient gravels - watershed of Tyung and Markha Rivers[5]
SiO_2	0.40	0.10	2.00	-	-	-	0.14	0.20
TiO_2	47.95	46.33	50.00	53.79	49.27	49.32	49.89	52.80
Al_2O_3	-	-	-	-	-	-	0.02	-
Fe_2O_3	13.15	17.96	10.80	7.05	11.27	14.30	6.26	9.96
Cr_2O_3	0.75	0.41	-	-	0.63	-	-	-
FeO	28.00	26.29	28.80	27.05	29.34	28.18	40.39	33.84
MnO	-	-	-	-	0.29	-	0.41	0.28
MgO	9.00	8.60	9.00	12.10	8.87	9.00	2.27	1.04
CaO	traces	traces	-	-	0.13	-	0.34	1.84
V_2O_5	0.20	0.20	-	-	-	-	-	-
Nb_2O_5	0.13	-	-	-	-	-	-	-
H_2O	-	-	-	-	-	-	-	0.18
Total	99.58	99.89	100.60	99.99	99.80	100.80	99.72	100.14
Specific gravity	4.58	4.61	4.42	4.436	4.566	4.566	-	-

Analysis by [1]K. A. Baklanova, [2]After A. F. Williams, [3]After P. A. Wagner, [4]E. A. Vinent, [5]V. O. Bugrova

TABLE 10. Mineral components of ilmenite from various deposits

	Specimen no. *							
	1	2	3	4	5	6	7	8
Crichtonite	58.7	57.3	62.5	53.6	59.3	56.3	86.2	75.1
Geikielite	34.7	33.5	30.8	42.8	33.1	34.5	8.7	4.1
Pyrophanite	-	-	-	-	0.6	-	0.9	0.6
Rutile	-	0.1	2.0	-	-	2.3	-	10.1
Perovskite	-	-	-	-	0.3	-	0.9	5.1
Magnetite	1.0	0.1	-	1.2	1.8	-	0.6	-
Hematite	5.0	8.7	4.7	2.4	4.3	6.9	2.7	5.0
Chromite	0.6	0.3	-	-	0.6	-	-	-
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

* Specimens are numbered as in Table 9.

Components such as magnetite, rutile, perovskite, and chromite are indicated only tentatively, because exact amounts of the corresponding oxides in ilmenite are unknown. Mineralographic studies on a number of specimens indicate ilmenite to be fundamentally homogeneous; parting of tiny magnetite grains along specific directions, caused evidently by separation from solid solution, was observed in only three specimens (from "Zarnitsa" deposit).

It is significant that ilmenite from Siberian kimberlite contains certain quantities of chromium and vanadium; "Zarnitsa" deposit also contains niobium. Moreover, a large number of spectrum analyses indicate that ilmenite has very low nickel content (0.001 - 0.003 percent).

Olivine: It was stated earlier that olivine occurs most commonly in "Dalnyaya" pipe eluvium, where it amounts to 40 - 50 percent of electromagnetic fraction of concentrate.

Olivine grains are usually shapeless, with somewhat rounded edges; and are colorless, weak yellow, or yellow-green; grain surfaces are matt [Ed.: dull?], as if caused by resorption. Average size of olivine grains is 0.5 - 2 mm. Olivine has the following optical constants: $N_g = 1.690$, $N_p = 1.652$.

Table 11 shows chemical composition of olivine from "Dalnyaya" pipe; for purposes of comparison, chemical analysis results are given for olivine from De Beers mine, South Africa.

The most striking fact from Table 11 is high magnesium-oxide content of olivine; this mineral is in chemical composition and in optical content, intermediate between forsterite and chrysolite.

Very low calcium content results, evidently, from accidental inclusion of a few diopside grains when material was taken for analysis (very small diopside grains are difficult to distinguish by color from those of olivine). Presence of iron and aluminum oxide in very small amounts and, of chemically combined and absorbed water is connected apparently with thin stringers of serpentine and iron hydroxide observable in olivine grains. Table 12 recapitulates analysis results for olivine in terms of a crystallochemical formula.

TABLE 11. Chemical composition of olivine

Components	Olivine from "Dalnyaya" pipe[1]	Olivine from De Beers m. S. Africa[2]
SiO_2	40.82	40.27
TiO_2	traces	-
Al_2O_3	0.09	-
Fe_2O_3	1.14	2.21
FeO	8.06	7.14
MnO	0.06	traces
MgO	49.10	48.61
NiO	-	traces
CoO	-	traces
CaO	0.70	-
H_2O	0.27	1.10
Others	0.44	-
Total	100.68	99.33

[1]Analysis by V. D. Bugrova
[2]After P. A. Wagner

A few grains of olivine were observed in the concentrate from "Zarnitsa" kimberlite pipe. These grains are very small (1 - 3 mm), shapeless and semitransparent, with a matt [Ed.: dull?] surface; color ranges from almost colorless to olive-green, although most grains are pale, green-yellow.

Presence of fairly large quantities of olivine in "Dalnyaya" pipe eluvium suggests the existence of virtually unaltered kimberlite at slight depth below the surface.

TABLE 12. Recapitulation of the chemical analysis of olivine

Composition	% by weight	Number of molecules	Number of oxygen atoms	Number of oxygen atoms combining with:				Number of oxygen atoms calculated on basis of 4*	Number of cation atoms in olivine
				serpentine	diopside	iron hydroxide	olivine		
SiO_2	40.82	679	1358	12	26	-	1320	2.01	1.00
TiO_2	traces	-	-	-	-	-	-	-	-
Al_2O_3	0.09	1	3	3	-	-	-	-	-
Fe_2O_3	1.14	7	21	-	-	21	-	-	-
FeO	8.06	112	112	-	-	-	112	0.17	0.17
MnO	0.06	-	-	-	-	-	-	-	-
MgO	49.10	1218	1218	15	13	-	1190	1.82	1.82
CaO	0.70	13	13	-	13	-	-	-	-
H_2O	0.27	14	14	-	-	14	-	-	-
Others	0.44	24	24	24	-	-	-	-	-
Total	100.68		2763	54	52	35	2622	4.00	

*Common factor 4:2622 = 0.0015

Crystallochemical formula of olivine:

$$Mg_{1.82}Fe_{0.17}) [SiO_4]\ 0.08\ \{(MgAl)_3\ [OH]_4\ [Si_2O.5]\}0.07\ \{CaMg\ [Si_2O_6]\}0.05\ \{Fe_2O_3 \cdot nH_2O\}.$$

Magnetite: Comparatively widespread in kimberlite. There are two genetic types of magnetite: 1) magnetite formed contemporaneously with the rock, and 2) magnetite formed in the serpentinization process.

Magnetite of the first type occurs primarily as angular grains or as crystal fragments; commonly these grains make up the rock texture. Some larger aggregates exhibit radiating structure. Commonly, finely dispersed magnetite occurs as fine-grained accumulations on the periphery of cryptocrystalline serpentine aggregates. Magnetite occurs also as reniform sinter with radiating structure. In places, very small, drusy magnetite nodules fill small cavities in kimberlite.

Table 13 and 14 show semiquantitative spectrum and chemical analysis results for magnetite from "Zarnitsa" and "Mir" kimberlite pipes.

Diopside and Chrome-diopside: In all the deposits under consideration, a few grains of diopside occur as angular fragments ranging from almost colorless to bottle-green, and are semitransparent to transparent. Grain size ranges from 2 to 5 mm. Grain surfaces, uneven and finely ribbed, exhibit vitreous luster in natural light.

TABLE 13. Results of semiquantitative spectrum analyses of magnetite*

Deposit	Components								
	Si	Al	Mg	Ca	Fe	Mn	Cu	Ni	Cr
"Mir"	0.1-1.0	0.01	0.1-0.3	0.01	>10	~ 0.01	0.001	0.001	<0.01
"Zarnitsa"	0.1-1.0	-	0.01-0.1	0.01	>10	0.03	-	-	-

* Analysis by Ya. M. Kravtsov.

TABLE 14. Chemical composition of magnetite*

Components	Deposit	
	"Mir"	"Zarnitsa"
SiO_2	1.56	0.20
TiO_2	0.40	0.80
FeO	25.20	27.93
Fe_2O_3	72.10	69.30
MnO	-	0.23
MgO	-	0.90
Total	99.26	99.36
Specific gravity	4.67	4.82 at 22°

* Analysis by V. D. Bugrova.

Optical constants for bottle-green diopside from "Zarnitsa" kimberlite pipe are as follows: $N_g = 1.712$; $N_p = 1.690$; $2V = +62°$.

Also, chrome-diopside occurs very rarely in "Mir" and "Zarnitsa" kimberlite pipes. Grain sizes, shapes, and surfaces are similar to those of diopside grains. Chrome-diopside

ranges in color from dirty yellow to emerald green. It has been mentioned previously that chrome-diopside occurs in large quantities in eluvium of "Zagadochnaya" kimberlite pipe, but most grains are shattered or are spotted with numerous fractures filled by gray-white decomposition products; this chrome-diopside is gray-green.

Emerald green chrome-diopside from the "Zarnitsa" kimberlite pipe has the following optical constants: $N_g = 1.706$, $N_p = 1.680$; pleochroic grass-green and pleochroic yellow-green, respectively; $2V = +63^o$.

A secondary mineral, which must be removed completely from chrome-diopside material taken for chemical analysis, has been determined as serpentine.

Chrome-spinel: A mineral of very rare occurrence, chrome spinel is found as small black grains (1.5 - 2 mm). In natural light, the grains are resinous black, but as transparent plates, brown-red. Chrome-spinel grains occur as small crystals, crystal fragments, or crystalline concretions, and have primarily octahedral faces, as well as combinations of cubic and octahedral faces. Frequently, edges of crystal faces are rounded, giving a characteristic elongated, rounded appearance.

TABLE 15. Chemical composition of chrome-diopside (eluvium of the "Zagadochnaya" pipe)[1]

Components	% by weight	Number of molecules	Serpentine	Chrome-diopside		
				Number of oxygen atoms	Number of oxygen atoms calculated on basis of 6[2]	Number of cation atoms
SiO_2	54.25	903	28	1.788	3.75	1.87
TiO_2	1.07	14	-	28	0.06	0.03
Al_2O_3	1.40	14	-	42	0.09	0.06
Fe_2O_3	1.50	9	-	27	0.06	0.04
Cr_2O_3	1.82	12	-	36	0.08	0.05
FeO	1.34	18	-	18	0.04	0.04
MnO	0.10	1	-	1	-	-
MgO	16.70	414	42	378	0.79	0.79
CaO	21.60	536	-	536	1.13	1.13
Na_2O, K_2O	traces	-	-	-	-	-
H_2O	0.05	3	3	-	-	-
Others	0.05	28	28	-	-	-
Total	100.33	1952	101	2844	6.00	-
Specific gravity	3.09					

[1]Analysis by V. M. Kovyazina. [2]Common factor 6:2844 - 0.0021.

Crystallochemical formula of chrome-diopside:

$$Ca_{1.13}\ Mg_{0.79}\ Fe^{..}_{0.04}\ (Cr_{0.05}Fe^{..}_{0.04})[Si_{1.87}\ Ti_{0.03}\ Al_{0.06}\ O_6] + 0.21\{Mg_3[OH]_4\overline{[Si\ O_5]}\}$$

Table 15 gives the chemical composition and crystallochemical formula for light green chrome-diopside from "Zagadochnaya" pipe eluvium. Chromium content of chrome-diopside is 1.82 percent; the crystallochemical formula indicates that this chrome-diopside contains a small amount of hedenbergite.

Table 16 shows the results of a semiquantitative spectrum analysis of chrome-spinel from various deposits.

TABLE 16. Results of semiquantitative spectrum analysis of chrome-spinels*

Deposit	Ti	Al	Mg	Mn	Cr	Ni	Fe	V	Co
"Zarnitsa"	0.1-0.3	0.1-0.3	3.0-6.0	0.01-0.03	>30	0.03-0.06	>10	0.03-0.06	0.01
"Mir"	0.1-0.3	-	3.0-6.0	0.01-0.03	>30	0.001-0.003	>10	0.06-0.1	0.01-0.03
"Zagadochnaya"	0.1-0.3	-	>6.0	0.01-0.03	>30	0.06-0.1	>10	0.06-0.1	0.01-0.03

* Analysis by Ya. M. Kravtsov.

These specimens of chrome-spinel, in their relatively high magnesium oxide content, approach magnesium-chromite.

Perovskite: At the present time, perovskite is known to occur only in the "Zarnitsa" kimberlite pipe, as very small cubic crystals (< 0.1 mm). Perovskite occurs somewhat more frequently as small crystals on ilmenite grain surfaces (fig. 12).

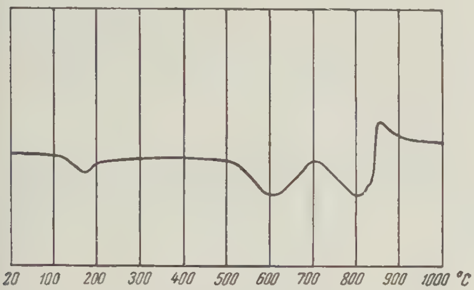

FIGURE 12. Differential thermal curve of chlorite

Table 17 gives the results of qualitative spectrum analysis for perovskite from "Zarnitsa" pipe.

TABLE 17. Results of qualitative spectrum analysis of perovskite from "Zarnitsa" pipe *

Elements	Si	Al	Mg	Ca	Fe	Mn	Ti	Ni
Content	+	traces	+	++	traces	traces	++	+

* Analysis by Ya. M. Kravtsov

Micas: In kimberlite eluvium, as well as in kimberlite itself, there are some occurrences of small yellow-brown or green phlogopite folia (N_m = 1.558). Phlogopite from "Zarnitsa" pipe is interleaved with chlorite replacements.

Both secondary and primary phlogopite occur in the kimberlite. According to A. P. Bobriyevich, primary phlogopite is characteristic of picritic porhyrite of apparently magmatic origin; the porphyrite occurs as fragments in kimberlite breccia. This is especially true in fluid picritic porphyrite; phlogopite plates are oriented roughly parallel to pyroxene microlites of the basic mass. Rarely, large olivine phenocrysts are surrounded by microliths of pyroxene and flakes of phlogopite.

Apparently, the larger segregations (2 - 4 mm) of phlogopite, occurring as variously oriented books of folia, are of secondary origin.

One of the pyrope grains (from "Zagadochnaya" pipe) was observed to contain phlogopite flakes within cracks in the crystal; this indicates secondary origin of phlogopite.

Biotite also is very uncommon; for the most part, it is associated apparently, with xenoliths in kimberlite. In eluvium of pipes, biotite occurs as small, flaky, golden-brown aggregates (N_m = 1.634). Thin biotite flakes occur in some serpentine grains and aggregates; an indication that biotite is of secondary origin.

A hydromica of phlogopitic composition - vermiculite: N_m = 1.564, - occurs in "Zagadochnaya" pipe eluvium. This hydromica, usually brown colored, on being heated becomes silvery-white as the mica swells.

Enstatite and Hypersthene: A single enstatite grain was found in eluvium of "Mir" pipe. This mineral is gray-white with a green tinge. Birefringence is low, extinction is straight, expansion is positive, N_g = 1.676, N_p = 1.666: this corresponds approximately to iron content amounting to 7 percent of the enstatite.

Hypersthene occurs with equal rarity. Altogether, only a few elongate, intensely shattered hypersthene grains were found by T. A. Bondareva in concentrates from eluvial and alluvial deposits of "Dalnyaya" pipe. This hypersthene is light gray with a faint green tinge; extinction is straight, the mineral is weakly pleochroic, N_g' = 1.706 and N_p' = 1.694.

XENOLITH MINERALS

Almandine: Fairly infrequently, almandine occurs in most deposits investigated; and, in appreciable amounts only, in "Zagadochnaya" pipe eluvium. Almandine ranges in color from bright orange to pale pink. As has already been noted in the description of pyrope, various quantities of almandine (N > 1.780) are present along with pyrope in eclogite inclusions ("Zarnitsa"). Red-orange almandine also occurs in certain crystalline schists, where it is associated with black (or almost black) hornblende and with feldspars.

Plagioclase: As white, acute-angled plates, plagioclase makes up almost the entire light fraction of concentrate from the eclogite-like rock ("Zarnitsa"). N_g = 1.548 and N_p = 1.539, indicating that the plagioclase is No. 25 plagioclase, i. e., oligoclase.

Hornblende: Single grains occur in the eluvium of "Dalnyaya" and "Zagadochnaya" kimberlite pipes. The hornblende is dark green, almost black; grains are angular fragments with well-developed cleavage at an angle of 56°. Hornblende from "Dalnyaya" pipe has the following optical constants: N_g' = 1.679, N_p' = 1.658. There is strong pleochroism from light green (at N_p') to dark greenish-gray (at N_p' [sic] refraction).

Apatite: In addition to pyrope, almandine, and plagioclase, apatite is present in eclogite as

white, elongate semi-rounded grains; its refractive indices are N_g = 1.634 and N_p = 1.631.

Tourmaline: One rounded, dirty green tourmaline grain, was found in the eluvium of "Mir" kimberlite pipe. Under the microscope, it was pleochroic from green-brown at N_m to brown-yellow at N_p; N_g - N_m = 1.656; N_p = 1.633.

Disthene: Single grains were found in eluvium of "Zarnitsa" and "Zagadochnaya" pipes. Grain sizes reach from 2 to 3 mm. The grains are light blue, tabular, and transparent having vitreous luster; N_g = 1.729, N_p = 1.710.

Zircon: Grains occur infrequently in almost all of the deposits; it usually is found as small (from 0.5 to 1.5 mm), acute-angled fragments. Color in zircon ranges from pale pink to almost colorless, with a strong adamantine luster; N_g = 1.781.

Rutile: Like zircon, rutile occurs at certain areas in the eluvium of all kimberlite bodies, as somewhat elongate, semi-rounded grains; its color ranges from red-brown to almost black, with a high luster.

Sphene: As single honey-yellow grains, sphene was found in crushing kimberlite from "Zarnitsa" pipe.

Spinel: Also as isolated, fragmental grains of octahedral crystals, pale yellow spinel has been found only in "Zarnitsa" kimberlite.

Grossularite: "Mir" pipe eluvium, grossularite occurs as very small (0.5 - 2 mm) crystals or fragments. Most grossularite grains are semi-rounded; although, frequently, well-preserved rhombododecahedral faces occur. Some grossularite grains have polyhedral, step-like pits, apparently produced by dissolution processes. Almost all grains show color zoning: from dark brown to black at the center, and brown- or green-yellow on the periphery.

In the light-colored outer zone, a refractive index N = 1.773 was determined.

Presence of well-developed grossularite polyhedra, along with rounded grains, suggests that grossularite may have been transported from nearby skarn formations, into kimberlite-pipe eluvium.

SECONDARY MINERALS

It has been mentioned previously that subsequent kimberlite alteration included extensive serpentinization and carbonization, as well as lesser degrees of silicification, chloritization, and pyritization. Minerals formed by these secondary processes are described below.

Serpentine: Distributed extensively over all deposits, serpentine commonly occurs in pipe eluvium as somewhat rounded, gray-white, pale green, dark green, yellow-brown or brown grains. Also, serpentine frequently forms pseudomorphs after olivine; in such cases, some crystal faces are so clear that interfacial angles may be measured by goniometer. Through study of these pseudomorphs in immersion preparations, it has been determined that they are nonhomogeneous in composition. The chief component, serpentine, has very low birefringence. In addition, however, there are considerable quantities of calcite (N_o = 1.666) and dolomite (N_o = 1.688); their presence is confirmed by chemical analysis (Table 18).

The kimberlite contains a number of irregularly shaped aggregates, as large as several centimeters across, composed of pale green or pale, cream-colored cryptocrystalline serpentine.

TABLE 18. Chemical composition of serpentine

Components	Specimen number and deposit			
	2s[1] "Mir"	3s[1] "Mir"	4s[2] "Zarnitsa"	5s[3] "Zarnitsa"
SiO_2	33.80	38.11	41.02	34.84
TiO_2	0.80	traces	0.06	0.21
Al_2O_3	0.57	-	-	0.50
Cr_2O_3	0.05	0.05	traces	0.05
Fe_2O_3	3.22	3.85	1.49	0.68
FeO	2.77	2.28	0.13	2.66
MnO	0.08	0.08	traces	0.06
NiO	0.21	0.20	0.24	0.21
MgO	31.53	33.30	41.05	31.22
K_2O	6.80	4.00	0.28	7.72
CaO	-	-	traces	0.10
H_2O(+105°C)	2.36	1.92	1.04	1.66
H_2O+	9.79	10.59	13.94	10.14
CO_2	9.28	5.85	0.96	9.87
P_2O_5	-	0.22	0.013	0.053
Total	100.54	100.45	100.20	99.97
Specific gravity	2.49	2.48	2.43	2.51

[1]Analysis by M. M. Stukalova
[2]Analysis by V. M. Kovyazina
[3]Analysis by K. A. Baklanova

Specimen 2s - light gray serpentine from "Mir" pipe eluvium.
Specimen 3s - dirty-green and brown serpentine from "Mir" pipe alluvium.
Specimen 4s - cryptocrystalline, pale, cream-colored serpentine from "Zarnitsa" pipe kimberlite.
Specimen 5s - light-gray and light-green serpentine from "Zarnitsa" pipe alluvium.

Table 18 shows chemical composition of all serpentine varieties present in the different deposits. These were recapitulated using V. S. Sobolev's method (1949), in the following crystallochemical formulas:

1) Specimen 2s:

$$(Mg_{2.51}Fe^{\cdot\cdot}_{0.14})(Al_{0.04}Fe^{\cdot\cdot\cdot}_{0.14})[OH]_4\,|\overline{\underline{Si_2O_5}}|\,0.43H_2O + 0.76CaMg \times [CO_3]_2 + 0.04\,SiO_2$$

2) Specimen 3s:

$$(Mg_{2.51}Fe^{\cdot\cdot}_{0.10})Fe^{\cdot\cdot\cdot}_{0,15}[OH]_4\,|\overline{\underline{Si_2O_5}}|\,0.27H_2O + 0.43CaMg[CO_3]_2 + 0.08\,SiO_2$$

3) Specimen 4s:

$$Mg_{2.93}Fe^{\cdot\cdot}_{0.04}[OH]_4\,|\overline{\underline{Si_2O_5}}|\,0.42H_2O + 0.06CaMg[CO_3]_2$$

4) Specimen 5s:

$$(Mg_{2.51}Fe^{\cdot\cdot}_{0.13})(Al_{0,03}Fe^{\cdot\cdot\cdot}_{0.02}Ti_{0.01})[OH]_4|\overline{\underline{Si_2O_5}}| + 0.81CaMg \times \times [CO_3]_2 + 0.12SiO_2$$

From these formulas, it is clear that serpentines from kimberlite are high in magnesium content. Constant presence in serpentines of very small amounts of nickel and, for a number of specimens, of chromium is noteworthy (Table 18).

Calcite: Generally represented by transparent or semitransparent crystal-cleavage fragments, calcite occurs in all of the deposits. Tiny scalenohedral crystals occur more rarely. Some calcite has been stained to cream or brown by iron hydroxides; commonly, calcite crystals and grains contain scattered, dark, opaque inclusions. Refractive index of calcite crystals has been measured as $N_o = 1.666$. Calcite druses saturated with bitumen (which has given calcite black coloration and greasy, even oily, luster) are present in "Mir" deposit. Table 19 shows chemical composition of calcite from "Mir" pipe.

TABLE 19. Results of chemical analyses of calcite (specific gravity = 2.73) from "Mir" pipe eluvium*

Composition	% by weight	Repeated at 100 %	Number of molecules	CO_3	$MgCO_3$	$SrCO_3$	$FeCO_3$
SiO_2	2.56	-	-	-	-	-	-
Al_2O_3	0.51	-	-	-	-	-	-
Fe_2O_3	0.07	-	-	-	-	-	-
FeO	0.14	0.14	2	-	-	-	2
MgO	0.78	0.80	20	-	20	-	-
CaO	52.84	54.59	974	974	-	-	-
SrO	0.43	0.44	4	-	-	4	-
CO_2	42.62	44.03	1001	974	20	4	2
Total	99.95	100.00	-	-	-	-	-

*Analysis by L. Chuyenko.

Crystallochemical formula for calcite:

$$(Ca\,0.974\;Mg\,0.020\;Sr\,0.004\;Fe\,0.002)\;CO_2$$

Presence of Mn in insignificant quantities has been determined by spectrum analysis. The differential thermal curve for calcite shows characteristic endothermal effect at 965°C; at this temperature, calcite decomposes.

Calciostrontianite: This mineral occurs only in "Zarnitsa" deposit. Calciostrontianite is found as closely adherent, radiating, aggregate, needlelike crystals; these are snow-white and sometimes stained to cream or yellow-brown by iron hydroxides. Commonly, these aggregates terminate in reniform sinters, are colorless or transparent, or, are stained red or brown by iron hydroxides. Rather large, snow-white, reniform calciostrontianite structures, usually terminating in druses of tiny transparent crystals, are present among aggregates of light-blue, macrocrystalline celestite.

Calciostrontianite is biaxial and negative with elongation negative; $N_g = 1.674$.

Table 20 shows results of semiquantitative spectrum analysis for calciostrontianite.

TABLE 20. Results of a semiquantitative spectrum analysis of calciostrontianite *

Elements	Si	Al	Ca	Ba	Sr
Content	0.1-1.0	0.01-0.03	$\gg$10	0.03-0.06	10

*Analysis by Ya. M. Kravtsov.

Dolomite: Occurs in large quantities in all of the deposits. In addition to its occurrence in large numbers of dolomitized-limestone xenoliths, (some very large), dolomite appears as fine-grained aggregates filling cracks in kimberlite or forming dense incrustations on surfaces of broken kimberlite blocks. These incrustations are gray-white but, most commonly, are stained yellow and brown by iron hydroxides; dolomite forming such crusts has refractive index N_o = 1.685.

Chlorite: Present in large quantities in eluvium of "Mir" kimberlite pipe; chlorite occurs as tiny, gray-green flakes having anomalous bluish tinge. Its refractive index is N_m = 1.595. Some thick, tabular chlorite bodies contain interfoliated carbonates: calcite (N_o = 1.666) and dolomite (N_o = 1.680). Table 21 shows chemical composition of chlorite, and recapitulation as crystallochemical formula. The latter indicates chlorite investigated here to be belong within the larger chlorite group, to magnesium variety.

TABLE 21. Results of chemical analysis of chlorite from "Mir" pipe eluvium [1]

Composition	Weight by 100%	Number of molecules	Number of oxygen atoms	Number of oxygen atoms calculated on basis of 9[2]	Number of Cation atoms
SiO_2	30.48	507	1014	3.42	1.71
TiO_2	0.32	4	8	0.02	0.01
Al_2O_3	8.42	82	246	0.82	0.54
Fe_2O_3	7.31	46	138	0.46	0.30
Cr_2O_3	0.26	1	3	0.01	—
FeO	6.81	95	95	0.31	0.31
MnO	0.06	1	1	—	—
NiO	0.13	1	1	—	—
MgO	25.18	624	581	1.95	1.95
CaO	3.70	66	—	—	—
K_2O	0.30	3	3	0.01	0.02
Na_2O	1.24	69	598	2.00	4.00
H_2O	11.13	619	619		
Others	4.83	109	218	—	—
Co, P_2O_5	traces	—	—	—	—
Total . . .	100.17	—	3105	9.00	—
Specific Gravity	2.62—2.67				

[1]Analysis by K. A. Baklanova.

$$\frac{-327\ (Ca,Mg)\ CO_3}{2778} = \frac{-90}{2688}$$

$$X = \frac{2mC-KA}{2m-K} = \frac{2\cdot 9\cdot 688-4\cdot 2778}{2\cdot 9-4} = 90;$$

$C-X = 688-90 = 598.$ [2]Common factor $2688 : 9 = 2.98$

Crystallochemical formula of chlorite:

$$K_{0.02}\ (Mg_{1.95}\ Fe^{\cdot\cdot}_{0.31})\ (Al_{0.32}\ Fe^{\cdot\cdot}_{0.30})\ [OH]_4\ \left|\overline{Si_{1.71}\ Ti_{0.01}\ Al_{0.22}\ O_5}\right|\ 0.3H_2O$$
$$0.3\ (Ca,\ Mg)\ CO_3$$

A differential thermal curve was constructed for chlorite, Figure 12. Thermal analysis was made in VSEGEI thermal laboratory under the direction of V. P. Ivanova. The first endothermic effect, occurring at temperatures ranging from 110 to 190°, corresponds to separation of absorbed water (confirmed by chemical analysis, see Table 21). The second and third endothermic effects, at temperatures ranging from 525 to 700°, are produced by separation in stages of chemically-bonded water; this is explained by different chemical bonds bonding this water to chlorite. At a temperature of 850°, the characteristic exothermic effect appears to be somewhat weaker as a result of an additional endothermic effect, ranging from 830 to 840°, related to carbonate dissociation; this effect could not be eliminated entirely in choosing the sample for analysis.

V. I. Mikheyev (of Leningrad Mining Institute X-ray structure laboratory) has made an X-ray analysis of chlorite; the results are shown in the Debye crystallogram, Table 22.

Distribution of lines and their relative intensities leaves no room for doubt that the specimen under investigation is, in fact, chlorite.

The Debye crystallogram for chlorite as a phyllosilicate, shows a clear line with distance between planes from 1.535 to 1.552, and a series of clear reflections representing different orders

TABLE 22. Calculation of Debye crystallogram of chlorite

Line no.	I	$\frac{d\alpha}{n}$	$\frac{d\beta}{n}$	Prochlorite		hkl	a
				I	$\frac{d\alpha}{n}$		
1	2	3	4	5	6	7	8
1	1	8.88	8.05	—	—	—	—
2	3	(7.97)	7.23	—	—	0.02	14.26
3	7	7.14	6.47	10	7.1	0.02β	14.28
4	1	5.00	4.71	4	5.2	—	—
5	8	4.77	4.32	10	4.72	0.03	14.21
6	1	4.56	4.13	—	–	—	—
7	3	(3.94)	3.57	5	3.93	0.04β	14.28
8	10	3.58	3.24	10	3.54	0.04	14.23
9	4	3.35	3.03	—	Quartz	—	—
10	4	(3.18)	2.886	1	3.12	0.05	14.430
11	1	3.01	2.727	—	—	—	—
12	10	2.883	2.613	7	2.83	0.05	14.415
13	2	2.660	2.411	1	2.69	—	—
14	6	2.570	2.330	5	2.55	–	—
15	2	2.456	2.226	5	2.44	—	—
16	6p	2.403	2.178	3	2.39	0.06	14.418
17	3	2.277	2.064	3	2.26	—	—
18	4	2.195	1.990	2	2.22	—	—
19	8	2.018	1.829	8	2.01	—	—
20	1	1.897	1.719	4	1.88	—	—
21	3	1.805	1.636	4	1.83	—	—
22	1	1.737	1.574	1	1.73	—	—
23	5	1.700	1.541	2	1.70	0.60	9.246
24	3	1.662	1.506	3	1.66	—	—
25	3	1.569	1.422	7	1.563	—	—
26	10	1.542	1.398	8	1.540	0.60	9.252
27	4	1.511	1.369	3	1.505	—	—
28	3	1.466	1.328	1	1.460	—	—
29	2	1.415	1.282	2	1.334	0.010	14.150
30	5	1.325	1.201	3	1.323	0.40	5.300
31	5	1.297	1.175	2	1.295	—	—
32	1	1.267	1.148	1	1.283	—	—
33	2	1.227	1.112	4	1.220	—	—
34	1	1.195	1.084	1	1.192	—	—
35	1	1.177	1.067	2	1.179	0.012	14.124
36	1	1.149	1.042	1	1.148	—	—
37	1	1.132	1.026	4	1.132	—	—
38	2	1.109	1.005	—	—	—	—
39	1	1.098	0.990	—	1.095	—	—
40	1	1.080	0.979	—	—	—	—
41	2p	1.046	0.948	—	1.043	—	—

of reflection from the basal pinacoid. On the crystallogram for the specimen under consideration, the line 1.542 and a series of short reflections are especially well defined. Important lines are indicated clearly; on the Debye crystallogram for this specimen symbols for plane lattices are given in Table **21**; it is clear from these that seven orders of reflection stem from the pinacoidal plane: 002, 003, 004, 005, 006, 0.010, and 0.012. It is easy to determine from these that the magnitude, C sin $\beta \cong 14.2$. When C sin β has a value equal to 14.150, the tenth order of reflection is the most reliable.

The well-defined line 010, with a distance of 1.542 between lattice planes, makes it possible to determine axis length in the unit cell for chlorite: b = 9.252 Kx; reflection 400 (line with distance between planes: 1.325 makes it possible to determine a sin β = 5.300 Kx. Thus, the unit cell for this chlorite specimen is accurately determinable.

Quartz and Chalcedony: Quartz occurs in large quantities in pipe eluvium.

Two types of quartz are distinguished: 1) quartz forming part of the xenoliths, generally appearing as tiny, cloudy, rounded grains; 2) quartz resulting from subsequent hydrothermal processes; this type sometimes occurs as well-formed tiny (to 2.5 mm) crystals with clear prismatic and rhombohedral faces, but, more commonly, as spindle-shaped crystal aggregates generally terminating in individual rhombohedral crystals.

Petrographic studies have shown some parts of the kimberlite to be strongly silicified.

Semi-rounded grains of dove-gray chalcedony, refractive indices N_g = 1.538 and N_p = 1.528, occur quite frequently in eluvial deposits.

Barite and Celestite: "Zarnitsa" pipe kimberlite contains celestite nodules; these take the form of tabular crystals held together in radiating aggregates (as much as 30 cm across). Celestite is light blue; more rarely almost colorless and, still more rarely, pink-gray or cinnamon. The refractive index N_g ranges between 1.629 and 1.633. Celestite aggregates, full of cracks, break up easily into small tabular grains.

Snow-white calciostrontianite is found commonly among celestite aggregates; in geodes, it has typical reniform appearance with radiating structure.

"Dalnyaya" pipe eluvium also contains very small tabular grains of light blue celestite (N_g = 1.630), and colorless, cloudy barite (N_g = 1.648).

Pyrite: Thin pyrite veinlets and nodules have been found in "Zarnitsa" and "Mir" kimberlite deposits. Pyrite nodules (2 x 6 cm in size) have radial structure. Eluvium from these pipes also contains tiny (to 2 mm) cubic pyrite crystals or spherical aggregates with radiating structure; these generally are covered with red-brown iron oxides.

Brown Iron Oxides: Of extensive occurrence, in all the deposits, brown iron oxides are the end product in dissolution of iron-bearing minerals.

Pipe eluvium contains yellow, brown or brick-red varieties of ochre-like iron hydroxide; brown, or dark brown, solid varieties which generally appear as rounded, cake-shaped grains with shiny surfaces; and, finally, grains with an alternation of ochre-like iron hydroxide and dark-colored solid hydroxide.

Many parts of the kimberlite are stained yellowish-brown by iron hydroxides.

CONCLUSIONS

The following points can be made in summarizing information above and in generalizing from results of this preliminary study on a number of Siberian kimberlite deposits:

1) Mineral composition of Siberian kimberlite is fundamentally similar to that of South African kimberlite.

2) As in South African deposits, such minerals as pyrope, olivine, diopside, ilmenite, and chrome-spinel have high magnesium content.

3) Mineral composition of various Siberian kimberlite deposits, like those of South Africa, fundamentally constant, differs only in relative amounts of one mineral occurrence or another; apparently, because of different conditions surrounding their formation.

4) Like South African kimberlite, Siberian deposits have undergone intensive secondary alteration; especially, serpentinization and carbonatization, with lesser degrees of silicification, chloritization and pyritization.

In conclusion, the author expresses his deep gratitude to Professor V. S. Sobolev for his invaluable advice during the writing of this article.

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CONTRIBUTIONS TO THE AGE AND ORIGIN OF THE SAN-MEN SERIES[1]

by

Wang Yun-sheng, Hu Huei-min and Lee Sheng-lin

• *translated by Royer & Roger, Inc.* •

ABSTRACT

New information on the San-men series of northern China has resulted from studies made in connection with the construction of the San-men gorge reservoir. The San-men sediments are predominantly lacustrine, partly fluviatile and deltaic. The environment of deposition was a lake controlled by the Wei-ho, Fen-ho, and Yellow River grabens. The San-men differs lithologically and structurally from underlying Tertiary beds. Early Pleistocene molluscs and vertebrate fossils have been identified. --M. Russell.

HISTORICAL BACKGROUND OF THE "SAN-MEN" SERIES

The name "San-men" series was proposed 40 years ago by Ting Wen-chiang and the Swedish geologist J. G. Anderson. During these 40 years, many Chinese and foreign geologists have studied and surveyed this area. As a result of the construction of the San-men gorge reservoir since liberation, many more have come and studied this area. There is, however, no general agreement or understanding as to the origin and age of the San-men series.

In 1918-1919, Ting Wen-chiang discovered the sand layer at San-men gorge and described the lithologic section. Soon later, Anderson found fossils from this sand layer and named it the San-men series.

The only fossil Anderson discovered was Lamprotula. In his paper, the Cenozoic of Northern China, the P'eng-t'i formation was regarded as lower or middle Pliocene, and the Chou-kou-tien formation as Pliocene. Therefore Anderson's San-men series comprises roughly the entire early Quaternary sequence. At that time, the meaning was clear and simple but the distribution, stratigraphy, and facies variations have not been adequately described [5].

Between 1923-1926, the French geologist Teilhand de Chardin, George Barbour and E. Licent, discovered the mammalian fauna at Hsuan-hua, Cho-tang and Sang-kan-ho and the Ni-ho-wan region. They found Hipparion together with genuine horse. They also found Lamprotula. Thus Ting Wen-chiang, Anderson and Teilhand de Chardin correlated the San-men series with the Ni-ho-wan series on faunal evidence to be the upper part of Pliocene (San-men series = Ni-ho-wan). The mammalian fauna is similar and equivalent to that of the Villafranchian, which is the upper part of Pliocene or the lower part of Pleistocene (Hipparrion + genuine horse = Villafranchian). The San-men series not only contains fossil molluscs but also a rich mammalian fauna. In fact, large amounts of fossil mammals similar to those of Ni-ho-wan were found near San-men. This series thus contains not only fluvial but also lacustrine deposits. The San-men series was thus established.

In 1935, Pien Mei-nien worked in the San-men gorge, Tung-kuan and Feng-ling-tu area. He divided the San-men series into an upper and lower part. The lower part is equivalent to Ni-ho-wan and the upper part to Chou-kou-tien (early Pleistocene).

The boundary between Pliocene and Pleistocene was discussed at the International Geological Congress in London in 1948. There were two schools of thought: one maintains that Hipparion should be the criterion to separate Pliocene from Pleistocene, the Hipparion-bearing beds belong to the Pleistocene. [Tr.: the original text uses the term "Pliocene", an error. If the word Pliocene is used here, the following will not make sense]. The other school of thought maintains that beds containing Bos, Elephas, and Equus should belong to the Pleistocene and those with Hipparion and Mastodon to the Pliocene. The first school of thought received majority support at the meeting, so that Villafranchian could also be early Pleistocene. In the San-men series, however, a fossil of the genuine horse type was found together with Hipparion. Later, based on the discussion of the International Geological Congress, the San-men series was designated the early stage of Pleistocene. From then on, based on the resolution of the International Geological Congress, the upper Pliocene (Ni-ho-wan) will be changed to early Pleistocene; Chou-kou-tien changed to middle Pleistocene and the Malan loess to late Pleistocene.

In 1954, Lin Tung-sheng of Academia Sinica did some work here and designated the lower

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[1]Translated from Ti-chih Hsüeh-pao: Acta Geologica Sinica, v. 39, no. 2, p. 167-184, 1959.

San-men series of Pien Mei-nien the San-men series proper and the upper San-men series, the Shan-hsien series of early Pleistocene age.

In 1955, a detailed geological survey was carried out by a large geological party surveying the geology of the San-men gorge area of the Yellow River. They once more revised the age of the San-men series, regarding it as early Pleistocene.

Forty years have elapsed since the discovery of the San-men series. Although much work has been completed during this period, actual accounts are scarce. Among the few papers we consulted, there is no agreement on the age of the San-men series. However, most workers agreed, and we think correctly, that the San-men series consists of fluvial and lacustrine deposits.

Anderson contended in his paper, the Cenozoic of North China, that the age of San-men series is post-P'eng-t'i series and pre-loess. His section, shown in figure 1, is oversimplified. It is actually much more complicated. This

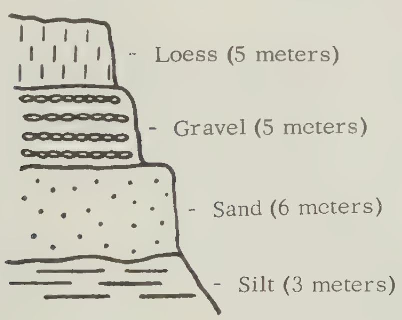


FIGURE 1. Anderson's San-men section.

section does not show the relation between and lithologic facies variations of the sediments.

The correlation of San-men series with Ni-ho-wan series (upper Pliocene) was mentioned in Yang Chung-chien's paper "A review of the history of the San-men series." It was proven on both the basis of fossils and lithology. Based on its fauna, Yang extended the San-men series farther down and the Chou-kou-tien series farther up the stratigraphic section contrary to Anderson's opinion. In this respect, Yang's idea is correct. He also discussed the older fossils such as Hipparion, Bos and the fossil mammal from Chi-lu, among the relatively recent faunal group of the Ni-ho-wan series. In the Chou-kou-tien deposits, older fossils are rare, most of the fauna is relatively recent, especially in the Peking-man locality. Doubtless, therefore, the San-men series should be older and Chou-kou-tien younger.

Following the resolution of the International Geological Congress of 1948 the Ni-ho-wan or San-men series should belong to early Pleistocene.

Yang also mentioned that the older fossils of Ni-ho-wan were not found in Chou-kou-tien and the younger fossils (a deer) from Chou-kou-tien has not been found in Ni-ho-wan. The bovine fossils of the two are also quite different. It would be logical to assume that there is a break or hiatus between the two. From our observations, we have not discovered any hiatus within the San-men series.

Pien's subdivision of the San-men series into an upper and lower part in 1935 was also discussed by Yang. Yang mentioned that he observed a distinct dip and a small anticlinal structure in the sand and gravel at Tai-ku and Yu-she area which were equivalent to Ni-ho-wan. Above this is a layer of red clay. There is also a basal gravel below the loess. The disturbance was restricted to the lower part, therefore a hiatus exists between the red clay and the sand and gravel. The section observed by us at Shen-miao-kou (Yu-wang-miao-kou) near San-men is not the same as that of Tai-ku and Yu-she. Both above and below the Ni-ho-wan sand and gravel with some clay are brownish red heavy clay layers with several layers of gravel. The brownish clay layer below is hard and compact with a high content of clay and abundant black manganese stain. Snails were observed in this clay. It is equivalent to the early Pleistocene brownish red clay which underlies the loess in eastern Shensi. The color and lithology are distinct from the early Tertiary purplish red clay or the red Hipparion clay of late Tertiary. A gravel layer below the lower brownish red clay lies with great angular unconformably above the early Tertiary, purplish-red clay. This entire section was disturbed. It forms an anticline. There was no break in sedimentation between the brownish red clays and the sand and gravel in the middle. The middle lenticular member thins out and the two red clays merge together, where it is in contact with the early Tertiary beds. Although there is a basal gravel layer it could be a facies change within the San-men series and does not necessarily represent a break.

In his paper "New structural movement in the San-men series" Liu Tung-sheng divided the San-men series into the lower San-men series of upper Pliocene age, and the upper Shan-hsien series of late Pleistocene age. Based on our observation at Yao-tou-kou, the Shan-hsien series of Liu Tung-sheng is the basal gravel which occurs at the base of the second terrace and belongs to the same stage as the overlying sand and loess of late Pleistocene age. This sand and gravel can be clearly observed and should not be confused with the basal part of the third terrace which does not

extend very far inward from the face of the section. In addition, on the basis of lithology, the kind of gravels, their shape and roundness and their degree of cementation, this gravel should belong to the second terrace, a point of view also concurred in by the geological party surveying the San-men gorge area of the Yellow River.

REGIONAL STRATIGRAPHY AND QUATERNARY PALEOGEOGRAPHY

The present area is situated south of the Ordos platform and the Shansi platform and north of the Tsingling axis. Its northwestern part traverses the Fen-wei graben.

The present geography is similar to the paleogeography. The area extends east-west between You-shan on the south and Chung-tiao-shan on the north. Its southwestern part lies north of Hua-shan and Li-shan and south of You-shan. Its northern part occupies the intermontane basin between Shansi and Shensi, south of Lung-meng-shan. You-shan, Hua-shan and Li-shan are parts of the Tsingling axis. Chung-tiao-shan is a part of the Chung-tiao-shan massif and Lung-men-shan is the southern rim of Ordos. Thick Quaternary sediments were deposited in this intermontane basin.

The paleogeography of this area can be divided into three periods:

Paleozoic: As a result of the Lu-liang movement of Sinian age, a large east-west sunken trough was developed, separating the Tsingling axis from the Ordos platform. Marine transgression brought in limestone, shale and quartzite nearly a thousand meters thick, deposited in rather deep water and in a hot climate. During Cambrian time, nearly 900 meters of oölitic and conglomeratic limestone were deposited and in middle Lower Ordovician time nearly 100 meters of thick and thin-bedded limestones were deposited. Because of the Caledonian movement, all of North China was uplifted to form the North China platform. Between late Middle Ordovician and middle Carboniferous, this was an eroded, old landmass. Upper Ordovician, Silurian, Devonian and lower Carboniferous rocks were therefore missing. During middle Carboniferous time, as a result of the Variscan movement, the central part of the North China platform began to subside once more. Hence this area became the southwestern part of a fluctuating shallow sea and adjoins the Tsingling old landmass. At the end of the Carboniferous period, the North China platform was slowly uplifted, accompanied by retreat of the sea. Many lakes and swamps were left on the platform. Permian beds were deposited conformably on the Carboniferous sediments.

Mesozoic: The entire period consists only of erosion without any sedimentation. Diorite and syenite porphyry were intruded along fractures during the early phase of Yenshan movement, forming dikes and stocks. The dam site of the San-men gorge reservoir is located on a diorite stock intruded into Permian-Carboniferous sediments. The huge; deep ruptures of this area developed during the last stage of the Yenshan movement forming the Fen-ho graben, the Wei-ho and the Yellow River graben and the horst of the San-men monoclinal structure.

Cenozoic: The Tertiary sediments of this region consist typically of thick red beds, deposited in continuously subsiding, inland basins. They were deposited in a hot climate under conditions of rapid erosion, and oxidation. They consist of thick red conglomerate sandstone, shale and clay with some gypsum.

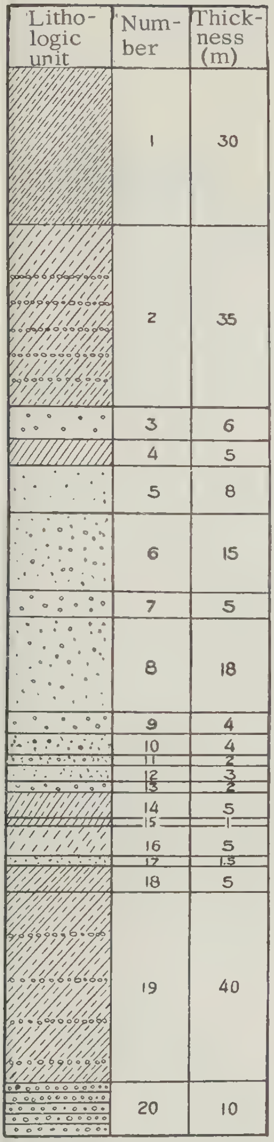
The Quaternary sediments were deposited in intermontane basins formed by Tertiary Himalayan faulting. They consist of light-colored, unconsolidated sediments deposited during a rather mild climate. The San-men series of early Quaternary was deposited in an inland lake in an intermontane basin.

The San-men lake was situated within the three grabens of Wei-ho, Yellow River and Fen-ho. The sediments of the San-men lake came from the surrounding mountains, Tsingling, Chung-t'iao-shan and Peishan, etc., transported by streams draining into the lake.

Near the end of the deposition of the San-men series, flood-plain deposits filled the middle Quaternary basins. Wei-ho and the old Fen-ho were formed at this time. Headward erosion developed the San-men gorge. Headward erosion of streams above the San-men gorge cut through the mountains between Shensi and Shansi and by piracy captured the stream flowing from Inner Mongolia. Thus, the Yellow River appeared toward the end of the Quaternary. Much of the flood-plain deposits consists of reworked loess, which filled and built up the vast plain between the mountains.

During late Pleistocene time, the climate was mild and humid, with abundant rainfall. The drainage system began to develop into its present pattern and began carving and eroding of the intermontane plains and basins. We think that Wei-ho came into being first, followed by Fen-ho and then the Yellow River. Uplifts of Ku-feng-shan, Chi-yu-shan and Tze-chin-shan toward the end of the Quaternary caused the old Fen-ho (today's Su-shui) to change its course and drain into the Yellow River at its present junction.

Within the Recent epoch, uplift and subsidence continued. Chung-tiao-shan continued to rise and the Fen-ho graben continued to sink.



Lithologic Description

1. Medium-plastic to plastic clay: light brown, intercalated with gravel and sand; gravel decreasing upwards. The medium-plastic clay has a platy structure; manganese stain rare, with small amounts of sand and gravel.
2. Medium-plastic to plastic clay: with five intercalated gravel layers; calcareous concretions more abundant in the upper part. Color of the clay, light brown; platy, highly calcareous and contains small amounts of black stain. Pebbles of the gravel layers consist mainly of metamorphic rocks with conglomerate fragments, limestone and granite, etc. The gravel is cemented by calcareous material and small amounts of sand.
3. Gravel: intercalated with thin layers of red clay and calcareous clay. The gravel consists of poorly sorted angular pebbles, cemented by calcareous material.
4. Clay: with thin calcareous seams, light brown, contains a few lenticular concretions.
5. Fine sand: with thin beds of hard sandstone, calcareous cement; sandstone is brown and hard; more abundant lenticular clay concretions above the sandstone.
6. Sand: brownish-yellow, even-grained, with thin beds of hard sandstone, some cretions and gravel.
7. Gravel: well-cemented; with sand and thin calcareous layers, some concretions.
8. Sand: intercalated with gravel and lenticular, hard sandstone.
9. Sand: relatively loose; with small amounts of clay fragments; upper part contains wedge-shaped, thin, clay layers.
10. Gravel: mostly clayey gravel, angular pebbles, poorly sorted, with a calcareous cement.
11. Sand: brownish-yellow, with lenticular clay and gravel layers. The sand part is loosely cement, cross-bedded.
12. Sandy gravel: rusty-colored sandy layer, poorly sorted, cross-bedded.
13. Gravel: angular pebbles, calcareous cement.
14. Brown medium-plastic clay: with grayish-green bands, shrinkage cracks common.
15. Clay: light red, hard, with manganese stain.
16. Medium-plastic clay and very fine sand: brown color with small amounts of calcareous matter.
17. Fine sand: well-sorted, hard, calcareous cement.
18. Medium-plastic to plastic clay: with black spots and some sandy gravel.
19. Plastic clay: brownish-red, with black manganese spots, some grayish-green bands. The plastic clay commonly sandy and gravelly. Three or four seams of calcareous concretions and three or four beds of gravel occur near the base. Pronounced lateral facies variation.
20. Gravel: cliff-forming, hard gravel, calcareous cement.

Total thickness: 205 meters

FIGURE 2. Columnar section of the San-men series near Shen-miao-kon and Hung-tui-ho of Ping-lu-hsien.

Sediments from Chung-tiao-shan were transported and deposited at the outlet of the old Fen-ho, thus giving rise to the present Su-shui basin.

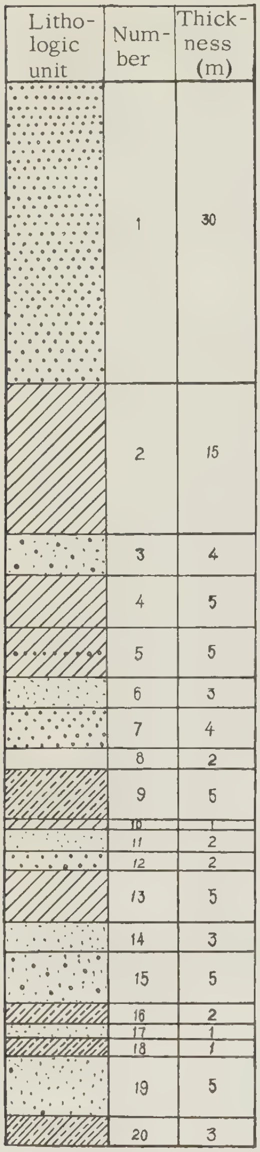
SAN-MEN SERIES AND ITS REGIONAL DISTRIBUTION

Due to the complex makeup of the San-men deposits its stratigraphic position, age, and origin, have not been established. Our field observations and analysis are given below in order to solve this problem.

The distribution of the San-men series is extensive and it has marked lithologic facies variations. Cross sections of various localities are given below.

Vicinity of the San-men gorge: The San-men gorge lies at the margin of the basin which is underlain by the San-men series. The margin of the basin is in contact with early Tertiary sediments, diorite porphyry and Carboniferous strata. The basin was occupied by a lake which broadens towards the west and contains sediments of an inland lake with constant facies variation and change in thickness. The stratigraphic relationship was further complicated by post-Tertiary structural disturbance.

Outcrops of the San-men series occur on both banks of the Yellow River near the San-men gorge. Based on stratigraphic position, lithology



Lithologic Description

1. Gravel: intercalated with rusty sand and clay lenses. Gravel essentially consists of limestone, sandstone and quartzite; sand and calcareous cement.
2. Plastic clay: light red, intercalated with thin gravel beds and lenses. Small amounts of black spots in clay.
3. Gravel: hard, calcareous cement; small amounts of light brown sand layers in the upper part.
4. Light brown, plastic clay with some sand and gravel.
5. Interbedded brown clay and gravel (three beds). Gravel is cemented by calcareous material.
6. Brown plastic clay, intercalated with thin beds and lenses of sand and gravel.
7. Sand and medium-plastic clay.
8. Gravel with calcareous cement.
9. Medium-plastic clay, yellowish-green, with organic matter.
10. Gray clay.
11. Yellowish-green, loose sand.
12. Well-cemented gravel, calcareous cement.
13. Highly calcareous, gray, hard clay with grayish-green spots.
14. Yellowish-green, grayish-green sand and medium-plastic clay layer, calcareous; with bands stained by iron oxide.
15. Yellowish-green sand with small gravel and hard sandstone and medium-plastic sand lenses with organic matter.
16. Medium sand, yellowish green and rusty color, interbedded with thin beds of hard sandstone lenses.
17. Yellowish green and grayish green, thin-bedded sand, well-sorted and with spotted iron stain.
18. Medium-plastic clay, grayish-green to yellow-green, with much organic matter; some rust-colored fine gravel.
19. Brown, loose sand with one thin lenticular bed of gypsum.
20. Grayish-green medium clay with intercalated thin sand lenses; contains iron stains and occasional thin gypsum layers.

Total thickness: 103 meters

FIGURE 3. Columnar section of the San-men series at Yao-tou-kou.

and color, the series consists of four units (figs. 2 and 3).

1. Conglomerate (basal conglomerate) 10-15 m thick. It is a hard conglomerate having a calcareous matrix and angular pebbles of various sizes. It forms a cliff and overlies the early Tertiary sediments unconformably (see fig. 4). This member occurs in the vicinity of Shen-miao-kou, Huang-tu-li-ho, Tung-po-kou and Pa-chih. It extends widely under the base of the fifth terrace and overlies the older basement rocks unconformably. The extent of this basal gravel is greater than the younger San-men sediments of the later stage, indicating that the inland basin was uplifted as sedimentation went on during the early part of the Quaternary period. The occurrence of the basal gravel outlines the pre-Quaternary topography. It lies nearly horizontally at the base of the fifth terrace, but the dip of the basal gravel locally reaches 30 degrees where the slope of the basement topography is steep.

2. Plastic clay layer interbedded with gravel: It is 40 to 60 m thick. The plastic clay is brownish-red, hard and blocky. It has a black manganese stain and contains fine gravel. Gravel layers and calcareous concretions are more abundant in the lower part. Grayish green calcareous spots and bands appear at certain horizons of this clay layer. The distribution of the gravel within it is irregular, more abundant and thicker in the lower part. It

[Photograph

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FIGURE 4. Photograph showing the unconformity between the basal conglomerate of the San-men series and the early Tertiary beds at Huang-tui-ho of Ping-lu-hsien.

consists of poorly sorted, angular gravel, poorly cemented by calcareous, clayey material. The variety of gravel depends on the source area and its location. For example, on the north bank of the Yellow River, most of the gravel consists of flat metamorphic rocks; and on the south bank, the gravel consists of essentially limestone and quartzite. This clay and gravel bed can be seen at Shen-mao-kou, Huang-tui-ho, Tung-po-kou and Wang-Kuan-kou, etc. areas (figure 5).

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FIGURE 5. Photograph showing the thin sand layers overlying the brownish-red plastic clay of the San-men series at Wang-kuan-kou of San-men gorge.

3. Gravel bed with intercalated layers of sand clay and heavy clay: It is from 40 to 70 m thick. The upper and lower part of the gravel contains thin beds or lenses of hard sandstone and has wide lithologic variations. This bed is exposed at Shen-miao-kou and Shih-pan-kou, etc.

The gravel layer sometimes contains clay and fragments and clayey gravel. Most of the gravel is angular and is cemented by sand.

The sand layer is yellow, flesh red or rust in color, well-sorted and loosely cemented. At certain horizons, it is cross-bedded, very similar to deltaic beds.

There are one or two layers of mollusc shell beds with San-men type of shells in the sand, clay and plastic clay layers. The sand is fine- to medium-grained, well sorted, loosely cemented and yellowish-green to flesh red. It is locally stained by iron oxide and contains lenses of gravel and clay.

The medium clay (Medium clay is a clay between a lean and.a fat clay. It is a loosely used term.), and clay is grayish-green, yellowish-green and brown in color. It contains a high amount of organic matter, spots and bands of iron oxide and is highly calcareous. It also contains a small amount of gravel and sand lenses.

This series of sediments is widely exposed at Huang-tui-ho, Yao-tou-kou, Tung-po-kou, and along the Yellow River westward to Min-hsiang and Tuang-kuan region. Because of lateral facies variations, this series is equivalent to the marginal gravels and were deposited contemporaneously.

4. Plastic and medium clay with intercalated gravel: It is 65 m thick, distributed in the Shen-miao and Shih-pan-kou region. It has a rather steep dip.

The plastic clay is light brown to brownish red, highly calcareous and stained by a few black spots. It has a scaly, weathered surface. Grayish-green spots and bands are rare. It contains a small amount of sand and gravel.

The gravel beds, up to five in number, are more abundant in the lower part and grade upward into beds of calcareous nodules. The poorly rounded gravel consists mainly of quartzite, with conglomerate limestone and granite fragments. It is loosely cemented by a calcareous and clayey matrix.

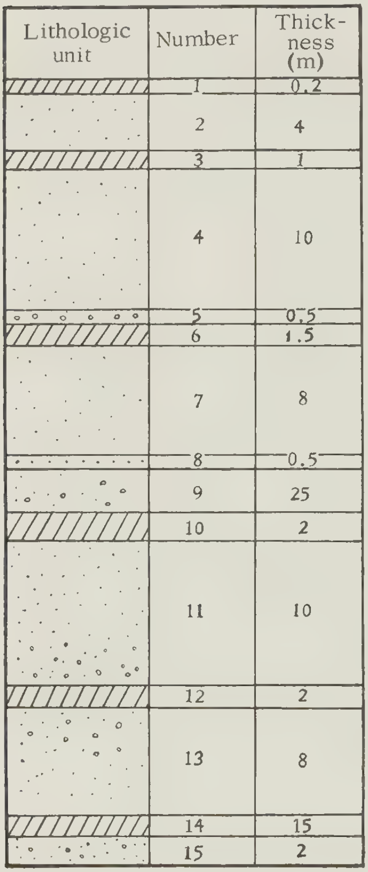
The above sections demonstrate the complex, lithologic makeup of the inland lacustrine facies, part of which may be deltaic.

Based on the vertical lithologic variation and variation of thickness, the lake basin varied in size during the sedimentation of the San-men series, closely responding to structural movement. The folding and fracturing shown by the section at Shen-miao-kou suggests relatively recent structural movement.

Workers in the past have considered the

basal gravel and the brownish-red plastic clay to be late Tertiary. Our present observation showed no hiatus in the sections and would not substantiate such a classification.

some iron oxide bands and some clay fragments. Clay, in the upper part, contains fossil snails which is equivalent to the Q_1 bed of eastern Shensi province.



Lithologic Description

1. Purplish-red clay of the erosional surface, containing abundant manganese stains and some fossil snails.
2. Grayish-yellow, well-sorted sand with intercalated clay lenses; loosely cemented.
3. Brownish-red, plastic clay.
4. Rice-yellow, well-sorted, loosely cemented sand consisting essentially of fine sand, intercalated with clay lenses.
5. Sand and gravel, poorly sorted and loosely cemented. Gravel fairly well rounded.
6. Dark brown calcareous clay, grading into sand below.
7. Flesh-red, cross bedded sand with rust-colored bands. Mostly medium-coarse sand with intercalated bean-shaped clay fragments oriented along cross-bedding.
8. Gray, hard sand, well-sorted, hard, calcareous cement.
9. Loose sand with small gravel, flesh red to brownish-yellow.
10. Gray, thin, platy clay, rich in organic matter.
11. Flesh red, even, granular sand incalated with hard sandstone and clay lenses. Fine gravel in the lower part, diameter of gravel from 1 to 5 cm.
12. Grayish-brown clay.
13. Sand and gravel, poorly cemented, intercalated with hard sandstone lenses.
14. Dark-brown, plastic clay with small amounts of black spots.
15. Loose sand and gravel, poorly sorted.

Total thickness: 53 meters.

FIGURE 6. Stratigraphic section of San-men series at Wu-wang-tu, Ling-chi-hsien.

The Wu-wang-tu section of Ling-chi-hsien (see fig. 6)

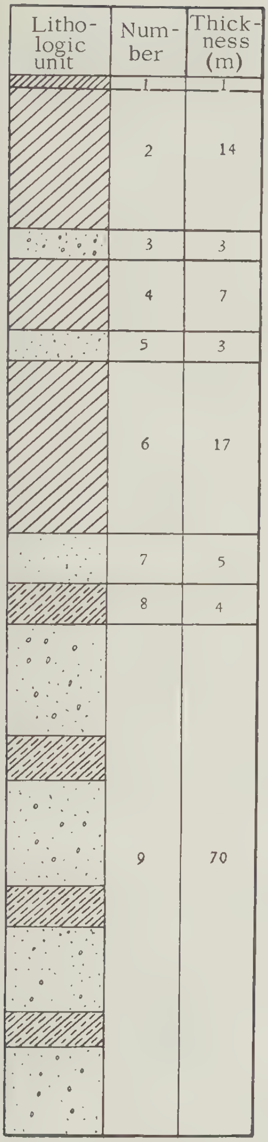
The section of Wu-wang-tu can be divided into two parts. The lower part consists of sand and gravel with thin layers of clay, 28 m thick. It is poorly cemented and contains lenses of hard sandstone. The gravel is well-rounded, from 1 to 5 cm [Tr.: meters in original] in diameter. The sand is of rust color, even granular and loosely cemented. The San-men geological survey party found deer antler, and fossil rhinoceros in the sand layer, which belong to Ni-ho-wan. The clay layers are grayish-brown to dark brown with small amounts of black stains, fine gravel and organic matter. The upper part consists of sand with thin layers of clay, 25 m thick. The sand is grayish yellow to flesh red, of fine, even granular texture, loosely cemented and crossbedded. It contains

The top clay layer is an erosional surface which represents the hiatus prior to the deposition of the loess above.

The San-men series observed in this section consists largely of fluvial deposits.

Section at Kuo-chi-chuang of Hua-hsien (see fig. 7)

This section can be divided into two parts on the basis of lithology. The lower part consists of sand with intercalated clay, from 50 to 70 m thick. The sand is yellowish-green to grayish-yellow, loosely cemented, and contains small amounts of gravel. The clay is grayish-green, highly calcareous and rich in organic matter, and in places with limonite stain. The brown clay is slightly calcareous, more compact and contains small amounts of gravel locally. The



Lithologic Description

1. Purplish-red clay with calcareous stringers, represents an erosional surface.
2. Brownish-red plastic clay with small amounts of manganese stains; chiefly quartz gravel and sand.
3. Sand with fine gravel, poorly rounded, chiefly quartz.
4. Plastic brownish-red clay with sand lenses. Clay contains spots of manganese stain, intercalations of sand and gravel.
5. Grayish-green and yellowish-green, medium-grained, loose sand.
6. Brown, heavy clay.
7. Loose, medium-grained sand.
8. Brown, medium-plastic clay.
9. Yellowish-green to grayish-yellow sand with thin seams of brown, plastic clay and grayish-green clay rich in organic matter. The calcareous sand contains small amounts of sand and gravel, coarser and more gravelly in the lower part.

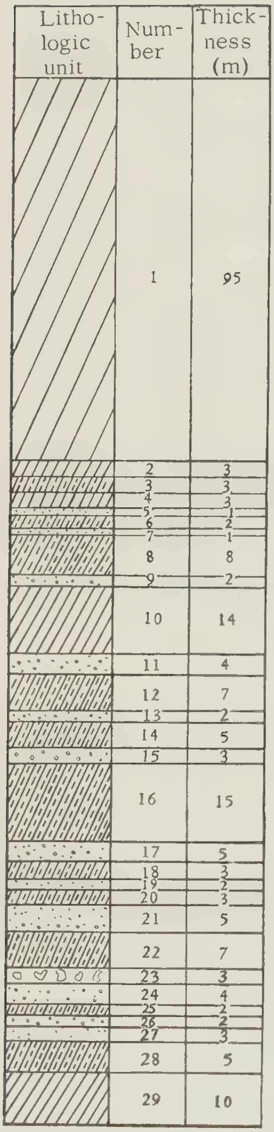
Total thickness: 126 meters.

FIGURE 7. Columnar section of the San-men series at Kuo-chia-chuang, Hua-hsien.

upper part consists of plastic clay with some sand layers, 54 m thick. The plastic clay is brownish-red, with some manganese stains, compact, blocky and contains small gravel and sand lenses. The sand is rice-yellow to grayish-green, fine-grained, loosely cemented and contains some gravel beds. There is a clay bed 1 m thick at the top. It contains stringers of carbonate and represents an erosional surface, a break in sedimentation.

Section at Hsieh-hu-chen of Lan-tien-hsien (figs. 8 and 9)

The San-men series is exposed in an anticline in the vicinity of Sha-ho-tze. Because of the effect of structural movement as shown by the anticline, the lithology and thickness are variable. Here, the San-men series is red, and resembles "red beds" in appearance. It is coarser in the lower part, grading upward into finer texture. The lower part consists of alternating sandy gravel and clay. The exposed thickness is 132 m. The gravel is poorly sorted and poorly cemented. It consists essentially of granite and metamorphic rocks. The sand is also poorly sorted, with grayish-green bands, and is crossbedded. The clay is brown, with calcareous concretions and grayish organic matter. The upper part consists of plastic clay with layers of calcareous concretions, 95 m thick. It is brownish red, compact, homogeneous, free of sand and gravel, and was probably deposited in calm lake water. The calcareous concretions are more abundant in the upper part. Four prominent beds can be observed, each from 1 to 2 m thick. At the top in contact with loess is a layer of purplish-red clay 1 m thick, underlain by a calcareous concretionary leached zone. The clay has an undulating surface, evidently representing an erosional surface.



Lithologic Description

1. Brownish-red plastic clay with manganese stains, more calcareous towards the top. Contains four layers of calcareous concretions. Clay is rather homogeneous without sand or gravel. Where in contact with loess (Q_{II}), the clay is redder and has a layer of calcareous concretions; this is the erosional surface.
2. Grayish-green clay, highly calcareous and high in organic matter.
3. Brown, medium-plastic clay.
4. Brown clay with small amounts of sand and gravel.
5. Loose, grayish-yellow, uniform, granular sand.
6. Light-red, medium-plastic clay.
7. Loose, gray, uniform granular sand, commonly has groundwater seaps.
8. Brown, medium-plastic clay with three layers of calcareous concretions plus small gravel. Some manganese stains.
9. Sand and gravel with a few loose pebbles, maximum diameter 1 cm.
10. Dark red clay with much black stain, blocky, intercalated with grayish-green calcareous clay rich in organic matter.
11. Brown sand and gravel. Gravel is of larger size, more rounded and commonly flattened and oriented.
12. Medium-plastic clay with thin sand layers; lower part purplish brown, contains abundant black stains. Coarser in texture upwards and grades into sand and gravel.
13. Sand and gravel; gravel is commonly flattened and oriented.
14. Brown, medium-plastic clay with two beds of calcareous concretions and thin seams of grayish-green clay with organic matter. The medium-plastic clay contains more manganese stains.
15. Loose gravel and sand, well-rounded, gravel from 2 to 5 cm. in diameter.
16. Brown, medium-plastic clay with much sand and gravel decreasing in amount upward. It has 4 layers of calcareous concretions with black stains and dendrite. Also intercalated with thin, grayish-green organic layer.
17. Sand, fine gravel in lower part grading into sand upwards; forms thin beds cemented by calcareous material.
18. Brown, medium-plastic clay with small gravel and thin grayish-green layers of organic matter.
19. Yellow sand, calcareous cement.
20. Purplish-brown, medium-plastic clay with black stains, with thin bands of grayish green organic matter.
21. Brown sand; lower part contains small gravel grading upward into sand and then into medium clay; gravel well-rounded.
22. Brown, medium-plastic clay with layers of calcareous concretions. Some black stain. Small amounts of organic matter near the top.
23. Thin beds of calcareous concretions.
24. Poorly cemented sand and gravel with broad cross-bedding. Gravel diameter from 1 to 2 cm. (Tr.: original text uses m. instead of cm.)
25. Dark brown, medium-plastic clay with some sand and gravel and black stained spots.
26. Gravel, calcareous cement. Gravel consists essentially of granite and metamorphic rocks.
27. Poorly sorted sand, calcareous cement, intercalated with grayish-green sand layers and elongated lenses.
28. Medium-plastic clay and sand, moderately well-cemented, with calcareous concretions and gravel.
29. Dark brown clay with small amounts of black stain, and sand and gravel.

Total thickness: 222 meters.

FIGURE 8. Columnar section of the San-men series at Hsieh-hu-cheng, Lan-tien-hsien

[Photograph not reproducible]

FIGURE 9. Photograph showing exposures of the lower part of the San-men series exposed by landslide at Hsieh-hu-cheng of Lan-tien.

The distribution of the San-men series is restricted to the grabens of Wei-ho, Fen-ho and the Yellow River, which were determined by ruptures. It is extensive in the area we surveyed. It occurs at the dam site of San-men in the east to Hsi-an and Lan-tien in the west. The distribution is restricted by the Wen-tang-tsun fault on the north bank of Wei-ho. It also

occurs along the north bank of the Yellow River. It occurs near Pao-ting and Chih-chuan-chen and is restricted on the south by Hua-shan and the Tsingling fault.

Near San-men, at the marginal area of the basin, the San-men series is about 200 m thick. At Hui-hsing-chen, drilling by the San-men gorge geological survey party to depths of 300 m did not reach its base. A hole near Hsi-an, drilled by the 901 troop of the Ministry of Geology, to depth of 470 m is still short of reaching the basement. A similar drill hole at Kang-ho-tsun of Lan-tien-hsien reached a depth of 471 m without penetrating the entire Quaternary sequence. Evidently the San-men series is of great thickness near the center of the lake basin.

The exposed thickness of San-men series varies geographically. The exposed thickness is small along the banks of the Yellow River; exposures are discontinuous along the banks of Wei-ho. It is covered by recent alluvial fans near Hua-yin and Hua-hsien. The best exposure, nearly 100 m thick, is located on the south bank of the Wei-ho. Fluvial deposits, equivalent with the San-men series but located outside of the graben area, occur at Pu-cheng, Pai-shui and Ho-yang. Their maximum thickness is about several tens of meters.

The sediments of the San-men series show distinct lateral and vertical variation. They are represented by coarser more complex association of sand and gravel along the marginal area of the lake, whereas near the center part of the lake the deposits are essentially fine-grained, represented by sand and clay. Coarse sediments such as gravel occur near the base, grading upward into sand, clay and plastic clay near the top. Such variations are typical of lacustrine sediments.

The dip of San-men beds also vary, for example, from 30 degrees in the marginal area, at San-men gorge, to 15 degrees at Tung-po. Westward, the dip becomes 5 degrees and in the interior the beds are nearly horizontal. Here, the sequence is orderly and the bedding is clearly marked. The facies show little variation. In the marginal area, however, beds of gravel and sand are irregular and show a great tendency to thin and thicken.

Based on the sequence of sedimentation, stratigraphic position and lithology, we have divided the San-men series of the reservoir area into three parts (see figs. 10, 11, and 12):

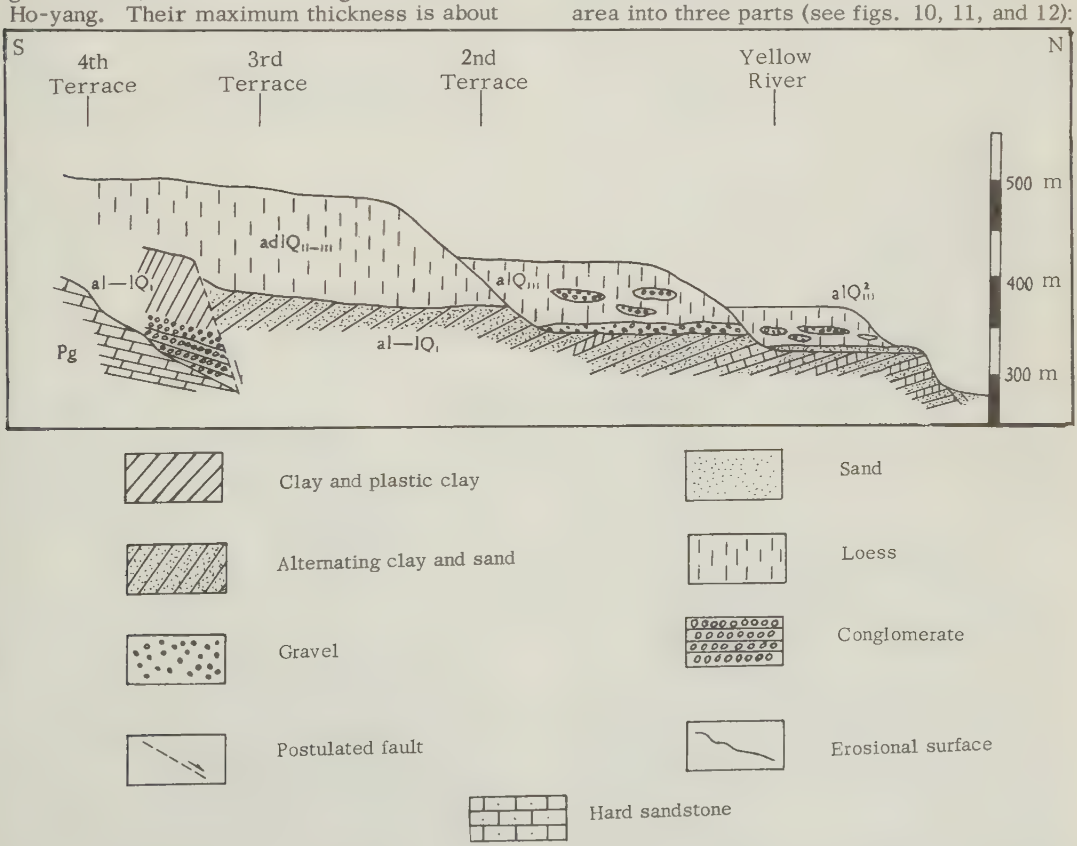


FIGURE 10. Schematic section showing the relation of terraces and the San-men series at Yao-kuan-kou.

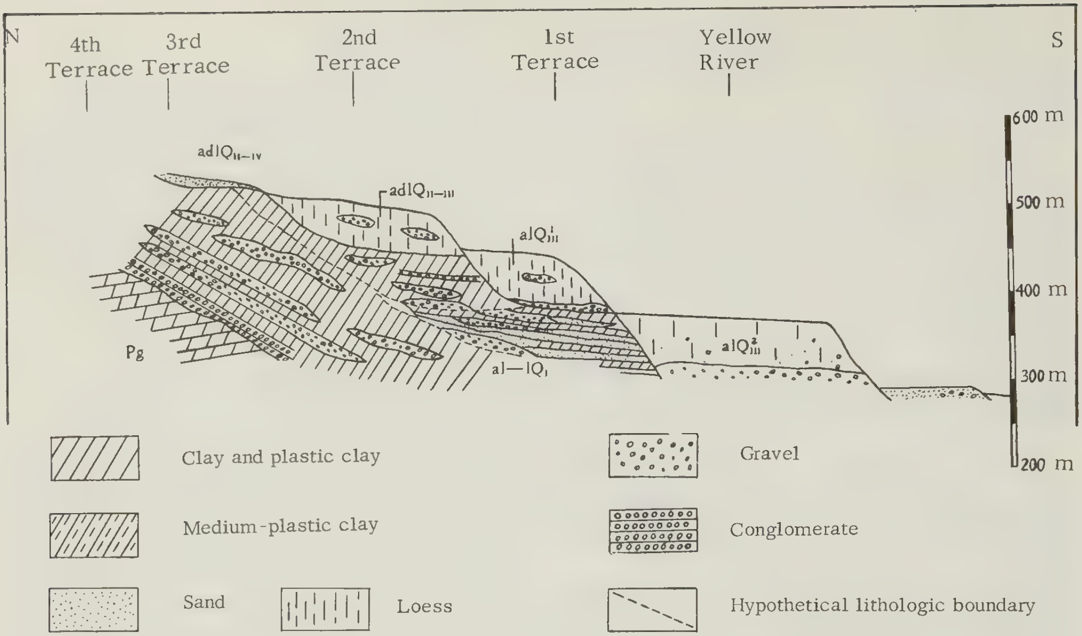


FIGURE 11. Schematic section showing the relation of terraces and the San-men series at Yao-kuan-kou.

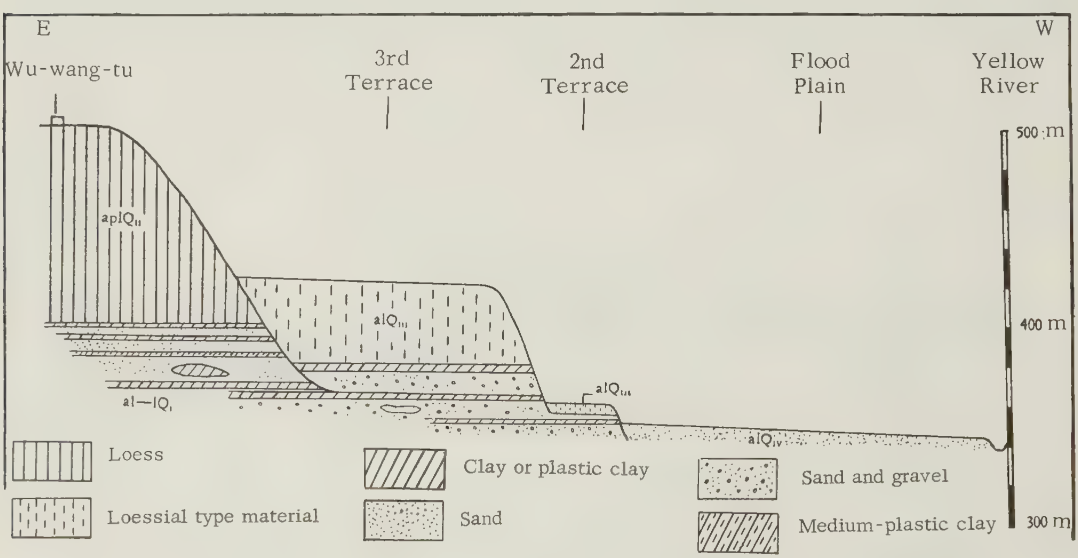


FIGURE 12. Schematic section of the Yellow River bank at vicinity of Wu-wang-tu.

1) Gravel of the lower part. It consists chiefly of gravel with intercalated plastic clay layers in the vicinity of San-men gorge, Ling-tung and Lan-tien (fig. 13). The main feature of this member is its coarse texture, reddish color, steep dip, and the occurrence of minor faults and small folds (fig. 14). The gravels are mostly angular, and of various sizes and poorly sorted. They are cemented by clay and calcareous material. The composition of the gravel is closely related to that of the basement rock it overlies. Thickness of exposed section near Lan-tien is 60 - 100 m. The section here was probably faulted, so the actual thickness is probably even greater.

2) Medium-plastic clay; other clay and sand, with small amounts of intercalated gravel layers in the middle part. It is widely distributed in the east of Tung-kuan (see fig. 15), in the Wei-nan region of the south bank of Wei-ho and in the Ta-li and Ku-shih-chen area of the north bank of Wei-ho (based on drilling done by the San-men gorge geological survey party).

The main features of this part of the section are: 1) The beds contain bands and patches of

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FIGURE 13. Photograph showing the gravel of the lower part of the San-men series at Chiang-kou of Ling-tung.

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FIGURE 14. Photograph showing the anticlinal fold in the gravel of the lower part of the San-men series near Ling-tung.

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FIGURE 15. Photograph showing the exposures of San-men series (section below the second terrace) along the river bank near Feng-ling-tu.

grayish-green to yellowish-green, calcareous clay with organic matter (generally 3 to 5 seams); 2) Limonitic bands are common in the sand beds; 3) They are predominantly composed of well-bedded, fine-grained sediments.

In the large area east of Tung-kuan, the thickness of the exposed section is generally from 10 to 40 m; the maximum thickness is 70 m. Intercalated gravel increases in amounts towards the margin of the basin. The grayish-green, medium-plastic organic clay and other types of clay increase in abundance from east to west. The exposed thickness in the Wei-nen area is about 100 m. The sequence consists of alternating beds of grayish-green and brown, medium-plastic clay. Here, the thickness of the brown and brownish-red, medium-plastic clay and plastic clay increases and the number of gravel beds decreases. Based on drilling, the San-men series occur at depths of from 20 to 30 meters below the surface in the Ta-li area, on the north bank of Wei-ho. It consists mainly of even-grained [well-sorted] loose sand with thin seams of clay. Gravel and the grayish-green clay with organic matter are rare.

3) Sand with intercalated medium-plastic clay and clay of the upper part. It is distributed along the banks of the Yellow River north of Tung-kuan; in the Su-shui basin and in the Chao-i, Hua-yang and Hua-hsien area. The main features of this part of the section are: (1) Flesh-red to rust-colored, thick, sand beds. The sand is loose and well-sorted, is fine to medium-grained, consisting primarily of quartz and feldspar. (2) Intercalated, hard sandstone beds occur in the sand or the clay bed. (3) The sand is crossbedded.

The thickness of this exposed upper part is about 50 m along the banks of the Yellow River, north of Tang-kuan. It decreases and disappears or thins out north of Pao-ting-chen. The disappearance may also be due to erosion by Fen-ho and its tributaries. On the basis of drilling data, it consists of fine- to medium-grained sand and is water-bearing in the Su-shui basin. The same beds were found by drilling at depths of from 20 to 30 m in the Chao-i and Hua-yang area. Here, the San-men series consists of abundant yellow, loose, fine-grained sand intercalated with thin seams of clay.

ORIGIN AND AGE OF THE SAN-MEN SERIES

After 40 years of study, there is no generally accepted conclusion as to the age of the San-men series. The results of studies of the past are arranged in table 1 to facilitate discussion.

You-shih-yuan (1958) has made the most recent contribution on the age of San-men series and he calls it Pliocene. We shall discuss our findings, particularly in view of You's recent contribution.

There are three major criteria used by You-shih-yuan: 1) According to the French author Mathews, the earliest horse did not exist until Quaternary time. Numerous Lamprotula have been found in the San-men gorge area; 2) Quaternary sediments are unconsolidated, whereas tertiary sediments are consolidated; San-men series is well consolidated; 3) the crustal movement in Quaternary is largely epeirogenic, whereas in Tertiary time orogenic movement was predominant.

TABLE 1. Age of San-men series according to different authors.

International age classification	Anderson 1918	Pien Mei-nien 1935	Yang Chung-chien 1936	Internat. Geol. Cong. 1948	Liu Tung-sheng 1954	You Shih-yuan 1958	Present authors 1958
Middle Pleistocene (Q_2)							
Lower Pleistocene (Q_1)	San-men series	Upper San-men series	Upper San-men series	San-men series	Shan-hsien series		San-men series
Pliocene (N)		Lower San-men series	Lower San-men series		San-men series	San-men series	

The sediments of the San-men series are steeply dipping; small folds and minor faults are present in them, therefore the series has been affected by orogenic movement. We feel that the use of these three criteria in proving that the San-men series is of Pliocene age is questionable.

Faunal evidence: In addition to Lamprotula, the San-men gorge geological survey party found other invertebrate fossils at Ping-lu of Shansi, Pu-cheng and Ta-li of Shensi, and Ling-pao of Honan province. The list includes: Lepidodesma cf. ponderosa Odhner; Corbicula largillierti philippi; Paludina sp.; Planorbis sp.; Succinea sp.

In addition, in the fine-sand beds of the upper part of the San-men series, the following vertebrate fossils have been found at Lang-tien-tsun of Wu-wang-hsiang of Ling-chi of Shansi province: Cervus (Eucladoceros) foulei; Coelodonta sp.

None of the invertebrate fossils found are index fossils, consequently, it would be difficult to determine the age on the basis of such fossils. It should be pointed out that Lamprotula not only lived in Pliocene fresh-water lakes, but also lives in lakes of today.

The two vertebrate fossils were identified by Chou-pen-hsiung and Chou-min-chen of the Vertebrate Research Institute of Academia Sinica and dated as early Quaternary. Moreover, they consider Cervus (Eucladoceros) foulei as a Quaternary index fossil.

Lithologic evidence: Many of the sediments of the San-men series consist of loose sand, gravel, and rock fragments, and intercalated clay. Only in the vicinity of the San-men gorge are there a few layers of consolidated rocks which are not particularly well cemented. In the vast reservoir area, consolidated sediments of the San-men series is totally absent. That Quaternary sediments are unconsolidated is actually the case here.

Structural evidence: We have also observed small folds and minor faults in the San-men series of the San-men gorge area. However, we believe that the minor faults observed along the banks of the Yellow River are the result of gravitational sliding; others are the result of recent movement. Faulting and folding of the San-men series in the San-men gorge area is exceedingly rare. The evidence for the existence of recent structural movement cannot easily be denied.

It follows, therefore, You-shih-yuan's assertion that the San-men series is Pliocene cannot be supported.

Based on the description of the lithology and vertebrate fossils above and the relation of the series with beds above and below, we believe that the correct age of the San-men series should be early Quaternary (Q_1), as did the 1948 International Geological Congress.

Although the San-men series has been subdivided by Pien Mei-nien, Yang Chung-chien and Liu Tung-sheng, as mentioned previously, we have not found any break in the section; consequently, we believe that the entire series should be early Quaternary in age.

Sung-chih-shen has studied the plant fossils and pollen of the San-men series but he has not reached any conclusions regarding its age. At present, it is more reliable to depend on pollen analysis for determining the Quaternary stratigraphy. The pollen analysis of San-men series should therefore be continued.

Most workers agree that the sediments of the San-men series are of fluvial and lacustrine origin, however, few have given any evidence of such an origin.

Our evidence for a fluvial and lacustrine origin is as follows: 1) Tracing the historical development of the basin as formed and restricted by subsided grabens, an inland lake basin became the site of deposition of the San-men series.

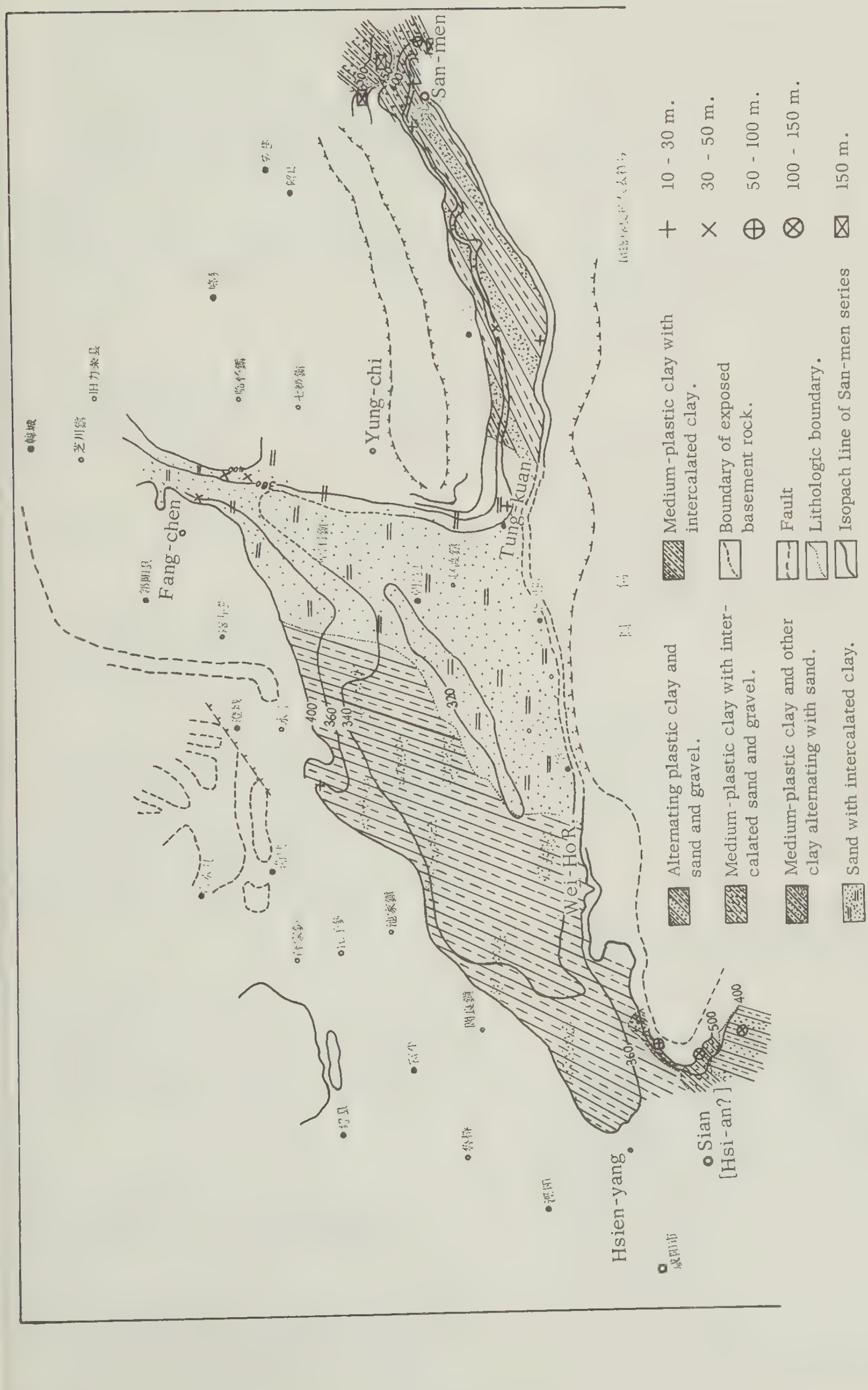

FIGURE 16. Lithologic distribution of the San-men series.

The entire series was therefore of fluvial and lacustrine origin.

2) The thickness and lateral facies change also prove that the sediments of the San-men series are lacustrine. Hsi-an is situated near the center of the San-men lake. The deposit found by drilling there is more than 400 meters thick. The deposits near San-men gorge are located along the margin of the basin where the thickness is about 200 meters. As mentioned previously, the lateral facies change is that of coarse material at the margin and fine material toward the middle of the lake.

3) In comparing various sections of San-men series the lithologic composition is not uniform (see fig. 16). This is because the different terrain that surrounded the basin was the source of sediment supply, a feature typical of a basin.

4) According to the description of the lacustrine facies of C. H. Yakovliev, the gravel, sand, rock fragments and the gastropod and pelecypod shells and gray clay they contain in the San-men series are typically lacustrine.

5) The well-sorted and well-rounded sand found at Wu-wang-tu of Ling-chi in Shansi province, probably represents the fluvial sediments of the San-men series. They were derived from the Permian and Triassic sandstones exposed at Ho-yang and Pu-cheng of Shensi province.

6) The black organic matter is more abundant in the lower part than the upper part of the brownish-red, plastic clay. This is the result of the decay of organic matter in the lake. Sung Chih-shen (1958) has shown that there was a rich plant population in the basin in San-men time.

CONCLUSIONS

The origin of the San-men sediments is lacustrine. It is in part fluvial as represented by stream and deltaic deposits of the basin. This conclusion is based on the following reasons:

1) Lithology: The San-men series is about 200 m thick. It consists of brownish-red clay and gravel in the lower part, light-colored sand and gravel with greenish clay in the middle part and brownish-red clay in the upper part. The composition of the sediments varies with the source of supply surrounding the lake. The sand, gravel, clay and the fauna they contain, are also typical of a lacustrine facies. The black stain found in the brownish-red, plastic clay may be either of organic origin or a manganese stain. Either of which is in harmony with the lacustrine origin of the sediments.

2) The altitude and the lithologic facies variation of the San-men series: Beds of the San-men series differ in attitude of dip and texture from the margin to the center of the lake. Beds dip about 30 degrees southwestward near San-men gorge, 15 degrees at Tung-po decreasing to 5 degrees to the west. In the large reservoir area in the center of the lake, the beds are nearly horizontal, sediments are more homogeneous, and bedding is clear and regular. The sediments near the margin of the lake in contrast, show complex variations. Gravel, sand and clay are irregularly distributed, alternating, with abrupt thinning and thickening, and are commonly cross-bedded. This is typical of lacustrine and deltaic deposits. The sediments are coarse-textured at the margin and fine towards the center of the lake; again, this is a characteristic feature of lacustrine deposits.

3) Paleogeography of San-men time: At the San-men time, the area was occupied by a large inland lake (or an intermontane basin). It was controlled by the Wei-ho, Fen-ho and Yellow River grabens, surrounded by mountains on all sides.

With regard to the age of San-men series, we believe that it should be early Pleistocene for the following reasons:

1) From the structural point of view, although minor faults and folds occur in the San-men series, they were the results of a new, recent movement of epeirogenic nature unlike the orogenic Tertiary movement.

2) The San-men series overlies Tertiary red beds with a distinct angular unconformity. Lithologically, it is also different from the Tertiary red beds. The color of the San-men series is lighter red. Although it contains brownish-red, plastic clay, it differs from the early Tertiary purplish-red clay and the late Tertiary, bright-red Hipparion clay in composition, as well as degree of cementation. The difference is primarily that of different paleogeographic environment.

3) From the faunal evidence, most of the molluscs and vertebrate fossils in the San-men series belong to early Quaternary. Among them, Cervus (Eucladoceros) foulei, according to Chou Pen-psuing and Chou Min-chen, is an index fossil of early Pleistocene.

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PRINCIPLES OF CLASSIFICATION AND NOMENCLATURE OF THE ANCIENT VOLCANIC CLASTIC ROCKS[1]

by

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• *translated by Research International* •

ABSTRACT

Volcanic clastic rocks comprise various rocks of clastic texture, formed as a result of volcanic activity. Classification of these rocks should be based, in the first place, on petrographical characteristics, which are possible to determine macro- and microscopically. In the suggested classification volcanic clastic rocks are subdivided into four groups, according to the composition of cementing mass and to the relative contents of pyroclastic and sedimentary material, namely: lava breccias, pyroclastic rocks (welded tuffs, tuffs, volcanic breccias), essentially pyroclastic rocks (tuffites) and pyroclastic-sedimentary (tuffogenic-sedimentary) rocks. Further subdivision of the rocks depends on their granulometric composition, chemico-petrographical composition and also on homogeneity or heterogeneity of the clastic material. In some cases there are also taken into account the relative contents of vitric, crystal and lithic pyroclastic material and the degree of abrasion and sorting of the fragments. -- Research International.

Recently, detailed geological investigations have broadened increasingly in scope; concurrently, the inadequacy of classification and nomenclature of volcanic clastic rocks, a wide group of clastic rocks formed as a result of volcanic activity, has become evident. Most existing classification schemes do not include all varieties of these rocks. In several instances, secondary criteria, or criteria which are difficult to determine, have been employed.

One of the first classifications was introduced by F. Wolf [17]. He organized volcanic clastic rocks into three groups: lava, ash, and mixed ash-sedimentary cements. Additional subdivisions, based on particle size, were schematic only. Classification according to particle size was developed in greater detail by subdividing loose products of contemporary volcanism into ash, sand, bombs and blocks, as has been proposed earlier by I. Walter and R. Shirmits in 1886, and by Jonet-Lewis in 1886. Similar work on particle-size criteria was used as a basis for the classifications of P.P. Gudkov [2] and C. Wentworth and H. Williams [16].

The Wentworth and Williams classification of pyroclastic rocks is primarily based on particle-size composition, secondarily, on the origin of pyroclastic material (essential, accessory, accidental); and, finally, on aggregate structure and petrographic composition of the fragments. This classification, simple in form and convincingly supported, is at present accepted in geological work, particularly outside the U. S. S. R. In our opinion, however, use of origin of material as a principal criterion is inadequate, because the question of origin in the case of pyroclastic material cannot always be resolved simply by petrographic methods. This very fact renders inadequate the recently proposed classification of V. A. Prokin [10, 11], who considers the origin of the material to be the most important criterion.

Wentworth and Williams, in their detailed consideration of exclusively pyroclastic rock, hardly touched upon a wide group of rocks intermediate between the pyroclastic and sedimentary rocks, or upon volcanic clastic rocks with lava cement. All these varieties of rocks were included in E. T. Shatolov's classification scheme [14], which included a new criterion: relative content of pyroclastic and normal sedimentary material in the rock. This criterion made it possible to distinguish tuffs (composed primarily of pyroclastic material), tuffites (a mixture of pyroclastic and sedimentary rocks), and tuffogenic (containing pyroclastic material in the form of admixtures only), and was widely used in the later classification schemes of E. F. Maleyev [6, 7], M. S. Shvedov [15], G. M. Saranchina [13], L. B. Rukhin [12], N. I. Nakovnik [9], V. N. Kirkinskaya [4].

The following classification (table 1) was compiled from data collected by members of the petrographic department at M.G.U. (Moskovskiy Gosudarstvennyy Universitet), on ancient volcanic series of the Altai, Kazakhstan, the Urals and the Caucasus; other classification schemes were also considered. The initial draft of this classification was discussed at a session of the Moscow Society of Naturalists [1].

Rocks are the chief evidence of ancient volcanic activity. For this reason, material composition and morphological criteria should be employed, and separated from classifications of contemporary volcanic products for which genetic descriptions will suffice. The rocks under consideration are, due to conditions of

[1]Translated from O printsipakh klassifikatsii i nomenklature drevnykh vulkanogennykh oblomochnykh porod: Sovetskaya Geologiya 1959, no. 5, p. 73-80.

TABLE 1. Classification of the ancient volcanic clastic rocks

Lava breccias: Uniform composition	Lava breccias: Non-uniform composition
Lava breccias	Agglomerate lava breccias
Petrographic composition is employed in rock name.	

Pyroclastic rocks				
	Tuffs and volcanic breccias			
Particle size in mm		Uniform composition		Non-uniform composition
> 200	Volcanic breccias	Volcanic block breccias		Agglomerate volcanic block breccias
30-200	Volcanic breccias	Volcanic breccias		Agglomerate volcanic breccias
5-30	Tuffs	Coarse-grained tuffs (including lapilli tuffs)		Coarse-grained agglomerate tuffs
1-5	Tuffs	Medium-grained tuffs	Granular	Medium-grained agglomerate tuffs
0.1-1	Tuffs	Fine-grained tuffs	Granular	Fine-grained agglomerate tuffs
<0.1		Very fine-grained tuffs	Dense	Fine-grained agglomerate tuffs
Welded tuffs (including ignimbrites and agglutinates)				
Petrographic composition is employed in rock name.				

Particle size in mm	Predominantly pyroclastic rocks (tuffites), sedimentary material not more than 50%
>30	Tuffite breccias
5-30	Coarse-grained tuffites
1-5	Medium-grained tuffites
0.1-1	Fine-grained tuffites
<0.1	Very fine-grained tuffites
Petrographic composition of pyroclastic material is employed in rock name, or is mentioned in description	

Particle size in mm	Pyroclastic-sedimentary (tuffogenic-sedimentary) rocks, sedimentary material greater than 50%	
>200	Tuffogenic boulder conglomerate and breccia	
100-200	Tuffogenic conglomerates and sandstones	Coarse pebbles (coarse-grained)
50-100	Tuffogenic conglomerates and sandstones	Medium pebbles (medium-grained)
10-50	Tuffogenic conglomerates and sandstones	Fine pebbles (fine-grained)
1-10	Tuffogenic gravelites and eluvial breccias	
0.5-0.1	Tuffogenic sandstones	Coarse-grained
0.25-0.5	Tuffogenic sandstones	Medium-grained
0.1-0.25	Tuffogenic sandstones	Fine-grained
0.01-0.1	Tuffogenic siltstones	
<0.01	Tuffogenic argillites	
Petrographic composition of pyroclastic material is mentioned in description		

their formation, transitional between magmatic and sedimentary rocks. Thus, their classification is based on criteria applying to both groups. The most important diagnostic criteria are: quantitative relationships between pyroclastic and sedimentary material in the cement, petrographic composition, particle size, uniformity and nonuniformity of composition of the clastic material. Secondary criteria are: aggregate structure, accessory material, and others used as supplementary characteristics.

Lava breccias, pyroclastic rocks (welded tuffs, tuffs and volcanic breccias), predominantly pyroclastic rocks (tuffites) and pyroclastic-sedimentary (tuffogenic-sedimentary) rocks are the categories for cement composition in the volcanic clastic rocks. By cementing material is meant that material between fragments, of all varieties, larger than 0.1 mm. The cementing mass can be lava (in lava breccias), ash particles and their hydrochemically altered products (in tuffs) as well as mixtures of pyroclastic and sedimentary (siliceous, argillaceous and calcareous) material.

Petrographic composition of the material, both fragments and cement, is an important criterion. It is used in naming the rock, as in lava breccias and tuffs, and in some cases, the tuffites. For tuffogenic sedimentary rocks, the composition should be included in the description.

Particle size is an important classification criterion for the majority of rocks in the groups under consideration, excepting the lava breccias and welded tuffs. The varied conditions of formation of pyroclastic and tuffogenic-sedimentary rocks result in different degrees of sorting, characteristic for each of the designated groups. Incomplete sorting, typical of the pyroclastic rocks, and especially the terrigenous extrusives, permits a rough division of the group according to size of the clastic material (see table 1). For this reason it is impossible to introduce further subdivisions corresponding to sedimentary rock classification. On the other hand, the tuffogenic-sedimentary rocks can be classified according to particle size, as accurately as can the sedimentary rocks.

In selecting terms, the authors avoided introducing new terminology, considering it advantageous to adopt existing terms; even if these are not completely adequate in this connection, they nevertheless have wide usage.

Rocks with volcanic fragments of different sizes cemented by lava are included in the breccia group. Petrographic composition is particularly important in this group, and in the lavas, to which they are related spatially and genetically.

The following divisions are made for lava breccias, according to the degree of uniformity of the fragmental material.

a) Breccias composed primarily of lava -- rocks in which the angular or partly welded or fused fragments and the lava cement have a similar or identical composition. Lava breccias frequently form on the surface of lava flows, during fracturing of the cooling crust. This is followed by the cementing of fragments in the crust by the same lava;

b) Agglomerate lava breccias, in which the fragmental material is of different composition. The fragments may all have the same composition but this differs from that of the lava cement. Agglomerate lava breccias can form either when lava engulfs fragments from the walls of volcanic pipes, or from surface lava flows, when lava engulfs underlying rocks (loose products of previous ejections, pebbles and fragments of various igneous and sedimentary rocks).

From various terms proposed by different authors (tuffo-lavas, clastolavas, pyroclastic lavas, agglomerate lavas and others), the term "lava breccias" most successfully expresses the basic properties of these rocks; the word "lava" indicates the nature of the cementing mass, while the word "breccia" indicates rock structure. The term "agglomerate" is used for lava breccias consisting of fragments with different composition (for instance, agglomerate andesite lava breccias containing fragments of granite and gneiss).

Rocks composed of cemented or welded pyroclastic fragments, and not including noticeable amounts of sedimentary material, are included in the pyroclastic group. Fragmental material from volcanic ejections, which is deposited more or less concurrently with the volcanism, is also designated as pyroclastic. Pyroclastic material does not bear any significant evidence of transportation and redeposition (lack of roundness, for instance). It is formed from ejected lava (bombs, lapilli, fragments of exploded glass, crystals, and solidified lava). It may be formed as a result of fracturing of the rocks composing the volcanic structure, as well as from various sedimentary, metamorphic, and igneous rocks contained in the substratum. In many instances, the pyroclastic fragments can be distinguished by their characteristic form or texture.

Welded tuffs (including ignimbrite formations) form a separate group within the pyroclastics. These rocks cannot be divided into different types according to grain size as the fragments have vague boundaries and commonly merge with the cement. Because of lack of information on the welded tuffs and ignimbrites, these rocks will not be further considered in this classification.

The main classification criteria for the

pyroclastic rocks are petrographic composition, degree of uniformity, and particle size. Two sub-groups have been formed, according to the degree of petrographic uniformity: a) tuffs and volcanic breccias, and b) agglomerate tuffs and agglomerate breccias.

Agglomerate tuffs and agglomerate volcanic breccias are distinguished [from tuffs and volcanic breccias] by the presence of fragments of non-uniform composition -- the fragments may be angular, smooth,or rounded. They may form as a result of replacement and movement of pyroclastic material from the flanks of volcanos by water, landslides, and slumps.

Degree of sorting of pyroclastic material depends on the medium in which it was deposited. Subaerially deposited pyroclastic rocks are distinguished by an almost total lack of sorting or bedding, while water-deposited rock usually displays better sorting and conspicuous bedding.

For the size classification of pyroclastic rocks the size nomenclature of loose products resulting from contemporary volcanic activity (ash, lapilli, bombs,and blocks) has been adopted. Rocks composed of the largest fragments (larger than 30 mm) are designated as volcanic breccias and the rest as tuffs. The boundary between volcanic breccias and tuffs corresponds to the boundary between bombs and lapilli.

The divisions for volcanic breccias are: a) volcanic breccias, particle size from 30 to 200 mm, b) volcanic block breccias, particles greater than 200 mm.

Tuffs are classified on the basis of particle size as coarse, medium, and fine-grained:

a) Coarse-grained tuffs, including lapilli particles ranging from pea size to walnut size (30 mm).

b) Medium-grained tuffs, greater fraction of grains from 1 mm to pea size (5 mm).

c) Fine-grained tuffs, particles ranging from the smallest visible to 1 mm.

d) Very fine-grained tuffs, grain size less than 0. 1 mm, not visible to the naked eye.

The same particle-size divisions are established for the agglomerate tuffs, with the exception of the very fine-grained type, which is not characteristic of these rocks.

Aggregate structure of pyroclastic material is not a main criterion, although so considered in certain classifications. Lithoclastic, crystalloclastic, vitroclastic and composite designations have been used in this connection. Results of studies of the volcanic series in Kazakhstan, the Altai, Urals and Caucasus have shown that tuffs are very commonly vitrocrystalloclastic. Thus, the forced introduction of this term is superfluous, and only tends to complicate the problem. While not objecting to the use of such terms as "litho", "crystallo" and "vitroclastic", their application should be limited to cases where they are absolutely necessary, for instance, in describing tuffs composed mainly of glass fragments (for instance, fine-grained dacite tuffs, vitroclastic).

From the above, it can be seen that the most widespread terms, such as "tuff" and "volcanic breccia" are included in the nomenclature of pyroclastic rocks. To designate the lack of uniformity in the particles of these rocks (in composition, form and size), as in the case of lava breccias, the term "agglomerate" is adopted.

The petrographic and particle-size composition of the principal constituents of fragments should be given (for instance, liparite volcanic block-breccia or liparite porphyry, coarse-grained agglomerate dacite tuff or dacite porphyrites).

Tuffites are essentially a pyroclastic group, composed of pyroclastic material (bombs, lapilli, volcanic sand, ash) with greater or smaller admixtures of sedimentary rock. The majority of authors concerned with the problem of classification and terminology of the pyroclastic rocks have agreed to this definition of "tuffite". However, on the question of establishing maximum admissable amounts of sedimentary material in the "tuffites", there is no agreement. According to E. T. Shatalov [14] and G. M. Saranchina [13], the amount of sedimentary material in the tuffites can range from 25 to 45 per cent, while E. F. Maleyev [6, 7] and V. A. Prokin [11] believe that the amount should not exceed 50 per cent. Obviously, the last point of view is more acceptable, as the border between tuffites and tuffogenic sedimentary rocks can be easily drawn, if we follow the principle that pyroclastic material predominates in tuffites (over 50 per cent), and sedimentary material predominates in the tuffogenic sedimentary rocks.

Tuffites formed in water, more or less contemporaneously with volcanic activity, are associated on one side with pyroclastic rocks and, on the other, with tuffogenic-sedimentary and sedimentary rocks. The mode of formation of tuffites results in bedding as well as a high degree of sorting.

Tuffite cement contains pyroclastic (ash) and sedimentary (argillaceous, siliceous, calcareous) material.

Frequently the pyroclastic material in

tuffites is so uniform in petrographic composition that this uniformity may be employed in naming the rock for instance, andesite tuffite or andesite porphyry tuffite, liparite tuffite or liparite porphyry tuffite. In cases where the pyroclastic material is mixed and in very fine-grained rocks where the precise determination of composition is difficult, the corresponding data are given in the description of the rock. The nature of the sedimentary material in the cement can be mentioned in the name (for instance, siliceous tuffite, argillaceous tuffite).

In some classifications it has been proposed that tuffites be classified according to particle size in the same way as tuffogenic-sedimentary rocks. Because the pyroclastic material in tuffites is the main component, and because the degree of sorting is close to that of the tuffs deposited in water, it is more feasible to divide them into coarse, medium, fine, and very fine-grained varieties as tuffs are divided. Most commonly the particle sizes in the tuffites do not exceed 5 or 10 mm, this being explained by the fact that tuffites usually form at considerable distances from volcano's centers, and thus where the largest fragments rarely occur.

Tuffogenic-sedimentary (pyroclastic-sedimentary) rocks are closely related to tuffites, but contain more sedimentary material (chemical, organic, clastic), pyroclastic material occurs only as an accessory (less than 50 percent). Very commonly the tuffite facies grades into the tuffogenic-sedimentary rocks with increasing distance from the center of volcanism. The tuffogenic-sedimentary rocks are commonly of considerable areal extent, forming a whole gradation of rocks approaching normal sedimentary composition. In many cases the tuffogenic-sedimentary rocks, as well as the tuffites, are associated with jasper and other siliceous rocks. The spatial relationships of tuffogenic-sedimentary rocks with tuffites and tuffs, together with the presence of pyroclastic material, is evidence of their genetic relationship with volcanic processes. A large amount of tuffogenic-sedimentary rocks with a given section is indication of contemporaneous volcanic activity. Thus it is necessary to distinguish the tuffogenic-sedimentary rocks from similar sedimentary rocks (for instance, graywacke), which form during erosion and redeposition of older volcanic formations. In connection with this, the tuffogenic-sedimentary rocks are considered in combination with earlier volcanic-fragmental rocks in a single classification scheme.

In classifying the tuffogenic-sedimentary rocks, together with the pyroclastic and predominantly pyroclastic rocks, they probably should have been called "pyroclastic-sedimentary." However, we have retained the old name, "tuffogenic-sedimentary," as a synonym, because this term has become strongly entrenched in petrographic literature and practice.

As sedimentary material comprises the bulk of tuffogenic-sedimentary rocks, and the pyroclastic is only accessory, they exhibit typically sedimentary textures and structures.

Usually the material is well-sorted, and bedding is sharply developed. Their close association with tuffites, pyroclastic and extrusive formations of related petrographic composition is in some instances, a deciding factor in assigning rocks to the tuffogenic-sedimentary group.

Tuffogenic-sedimentary rocks are subdivided into groups analogous to the sedimentary groups with respect to particle size, namely: tuffogenic boulder conglomerates and block breccias, tuffogenic gravelites [Ed: gravel conglomerate?] and eluvial breccias, tuffogenic sandstones, tuffogenic siltstones and tuffogenic argillites.

Insofar as the pyroclastic material is only accessory in the tuffogenic-sedimentary rocks, and does not determine the general structure of the rock, its chemical-petrographic description is not reflected in the name of the rock but is mentioned in the description, for example: tuffogenic conglomerate with an admixture of pyroclastic material of acid composition, tuffogenic siltstone with admixtures of pyroclastic material of andesitic composition.

The proposed classification allows classification of volcanic clastics into various tolerances, depending on the requirements of a particular geological investigation. Thus, in small-scale geological surveying (scales: 1:1,000,000 and 1:200,000) it suffices to distinquish only the main groups of these rocks (pyroclastic and tuffogenic-sedimentary). In detailed investigations it may be possible to distinguish smaller subdivisions according to the degree of uniformity in the pyroclastic material, the particle-size composition and the ratio of sedimentary and pyroclastic material.

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POSSIBILITIES OF FORMATION AND MIGRATION[1] OF OIL IN YOUNG SEDIMENTARY DEPOSITS

by

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ABSTRACT

Hydrocarbons, extricable by organic solvents, were found to occur in Recent marine sediments. The age of deposits under investigation here was determined by C^{14} method to be from 9, 000 to 14, 000 years, approximately. The problem of oil formation in these sediments is discussed in relation to accumulation rate of sediments and subsequent exposure of deposited material to bacterial action. Results of research on composition of gases present in various Recent deposits, and on that of gases formed by bacterial action on certain organic substances, established that methane formation is not accompanied by formation of heavier-hydrocarbon or gasoline-hydrocarbon fractions. Absence of C_3- C_{14} hydrocarbons (gasoline fractions) in Recent sediments, along with gaseous hydrocarbon fraction (characteristic of oil occurrence), indicates that oil formation processes do not occur in young sediments at shallow depth; but rather in sediments at considerably greater depth. Consideration of migrating oil as a possible sorption medium for the transport of light hydrocarbon fractions (on the assumption that the absence of oils in younger sediments may result from their sorption and removal by other media) lends further substance to this argument: Younger sediments, constituting a relatively low-temperature environment, are excellent sorption media and, therefore, are not conducive to oil migration. --D. D. Fisher.

It is common knowledge that some investigators regard the oil formation as a process occurring in the youngest sedimentary deposits; others believe that oil and gas formation does not occur until sedimentary deposits have submerged to substantial depth. The question concerning time and place of oil and gas formation and accumulation is associated closely with ideas on factors causing initial oil-mother substances to convert into oil and gas, and, with conditions surrounding their migration and accumulation.

Research on Recent marine deposits indicated that they contain decomposition products of proteins, carbohydrates, lignin-humus, and other compounds, as well as substances extricable by organic solvents including hydrocarbons. According to V. V. Veber, A. I. Gorskaya, V. A. Uspensky, and other investigators, the percentage of hydrocarbons, based on the dry weight of the sediment, amounts to 10^{-2} - 10^{-3}. The molecular weight of extracted hydrocarbons corresponds to 14 or 15, and more, carbon atoms per molecule. Recently, very detailed investigations were conducted by P. Smit; using the C^{14} method, he established the age of Recent deposits investigated to be from 9 to 14 thousand years. Presence of paraffinic, naphthenic, and aromatic hydrocarbons in these deposits was revealed in concentration of about 10^{-2} percent. A study on the hydrocarbons separated, indicated from 15 to 30 carbon atoms per molecule to be present.

Apparently, part of these hydrocarbons from Recent deposits occurred previously in living organisms; possibly, some hydrocarbons are formed in young deposits and rocks in the process of metamorphism of organic remains. Presence of the hydrocarbons indicated, serves as an argument used by some investigators who persist in their opinion that oil is formed in Recent deposits.

Researches on forms of organic matter in Recent deposits and on gas formation therein, are particularly interesting. Decomposition of the organic remains is caused principally by action of different bacteria present in hundreds of millions per gram of dry ooze from various reservoirs, or, in 1 gram of soil. Thickness of marine sedimentary deposits increases very slowly. Even near estuaries, e.g. the Volga estuary, increase in thickness amounts to only 2 or 3 mm per year. Consequently, organic remains and their decomposition products, buried in ooze, will be subjected for a long time to action by an enormous number of bacteria.

Under these conditions only those forms of organic matter will be conserved that are not affected by bacteria, as well as those particles of organic matter protected, as it were, by a film of a compound either destructive of bacteria, or not affected by them.

The C_{15} - C_{30} hydrocarbons present in Recent deposits cannot be regarded as oil; formation oils consist principally of light fractions and gaseous components. The most charac-

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[1]Translated from Problema Migratsii Nefti i Formirovaniya Skopleniy Nefti i Gaza [Problems of Oil Migration and Formation of Oil and Gas Deposits]: (Proceedings of a conference at Lvov, 8-12 May 1957), Moscow, Gostoptekhizdat, p. 59-63, 1959.

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teristic oil components are gasolines, kerosenes, and, as well, heavy hydrocarbon gases (propane, isobutane, butane); significant accumulations of these components only are present in oils. Modern analyses allow determination of individual compounds in oils. It was found that oils contain about 50 percent of the components mentioned (notably C_3 - C_{14}).

High-molecular-weight hydrocarbons from Recent deposits cannot be regarded as oil because the light fractions are absent; and, in particular, because the nature of these heavy hydrocarbons, having thousands of isomers, cannot be established; the question still remains as to whether these very hydrocarbons are present in oil It is common knowledge that various high-molecular-weight hydrocarbons are found in coal, peat, and in organic substances of both young and very old sedimentary deposits. Solid carbonaceous compounds, resembling several kinds of bitumens in their luminescent properties, are found as very small concentration (10^{-2} - 10^{-3} percent) in some igneous rocks. (In particular, investigations recently carried out by Moscow Geological Exploration Institute and(VNIGRI - All-Union Scientific Research Institute for Geological Survey) established the presence of similar bitumens and heavy hydrocarbons in igneous rocks of Khibin massive).

Consequently the problem involving presence in Recent deposits of petroleum is, first of all, connected with determination of light individual hydrocarbons, chiefly C_3 - C_4 and gasoline.

Investigation carried out under the author's guidance allowed determination of composition of gases present in ooze from various reservoirs and, in particular, in ooze from Recent marine deposits. Research into composition of gases formed by action of bacterial cultures on various organic substances also was carried out.

In these investigations, the main problem was to elucidate whether methane formation is accompanied by formation of heavier gaseous hydrocarbons and gasoline hydrocarbon components. Composition of both marsh gas and of gases present in a sorbed state in ooze and young deposits was investigated. In most analyses, samples were frozen at liquid-nitrogen temperatures. A heavy gas fraction in tubes cooled by liquid nitrogen contains heavy gaseous C_2 - C_4, and higher, hydrocarbons with an admixture of nitrous oxide. When concentration of heavy fraction was higher than usual, special analysis was performed in order to determine heavy hydrocarbons C_2 - C_4 in the presence of nitrous oxide.

Table 1 summarizes results for more than 450 analyses of gas from various reservoirs. When the error in concentration determinations of heavy fractions occurred within certain limits (approximately 0. 01 to 0. 02 percent and sometimes even lower), no special analysis was undertaken on C_2 - C_4 hydrocarbons.

Table 1 shows quantity of heavy fractions in the gases. Only 18 out of 450 gas samples examined had a very slight heavy-fraction concentration while two samples contained from 0. 1 to 0. 3 percent concentration.

More detailed analysis of these samples shows, principally, presence of nitrous oxide. In two cases only, traces of heavy hydrocarbon gases (C_2 - C_4 and higher), were found in areas which possibly could be regarded as oil bearing. Evidences of oil and gas were discovered afterwards in one of these marsh-ridden areas in Krasnodar district. Study of data obtained leads to the conclusion that formation of substantial C_2 - C_4 hydrocarbon concentrations, characteristic for oil, are observed neither in freshwater ooze nor in that of salt water reservoirs.

Composition of gases formed by Anaerobic-bacterial action, from marine ooze and sewage precipitations, on carbohydrates, organic acids, fats, proteins, and other substances was investigated. The ratio of individual bacterial-gas components changes with test conditions; however, percentage of heavy fractions did not, as a rule, exceed 10^{-3} percent. Four tests showed percentage to range from 0. 025 to 0. 05; only one percentage at 0. 1. More detailed analyses showed heavy fractions to contain nitrous oxide, apparently formed partially by nutrient substances added to bacterial cultures. Small ethane concentrations were obtained in two tests only (one from the cellulose samples, one from lard); heavier hydrocarbons (C_3 and higher) were not discovered. Stone, Sobell, and other investigators draw attention to the fact that, when fatty acids, leucine, tyrosine and phenylalanine are decomposed, no heavy hydrocarbon gases were found in gases of bacteriological origin.

Absence of light oil fractions in ooze and young sedimentary deposits indicates that basic oil-formation processes do not take place here, but at considerably greater depths. Intensive biochemical processes in young sedimentary deposits will not lead to oil formation.

It is possible that part of the high-molecular-weight hydrocarbons of young deposits may be solved in migrating oil; however, it is then essential that light, mobile oil fractions be formed.

Existence of favorable conditions for oil and gas migration and accumulation is a prerequisite for predestines for oil and gas concentrations. When considering oil formation from dispersed organic substances in rocks, the question arises as to how dispersed oil can accumulate; by its complexity, this question is connected primarily

TABLE 1. Composition of hydrocarbon gases formed in various reservoirs

District	Number of samples analyzed	CH_4 (average percent)		Heavy fraction (heavy hydrocarbon + N_2O)		Heavy hydrocarbon gases $C_2 - C_4$	
		Percent	cm^3/g	Percent	cm^3/g	Percent	cm^3/g
Moscow district, marsh gas	50	51	- -	0.01 and less	-	-	-
	2	20	-	-	-	-	-
Moscow district, gas from rocks at the bank of the Moscow river	24	0.0075	-	-	-	-	less than 0.002
Kalinin district, marsh gas	3	-	-	-	-	less than 0.003	-
Smolensk district, marsh gas	2	-	-	-	-	less than 0.003	-
Tula district, marsh gas	3	-	-	-	-	less than 0.001	-
Krasnodar district, marsh gas	134	64	0.01 and less	-	-	-	-
	3	-	0.06-0.08	-	-	-	-
Krasnodar district, gas from various reservoirs	13	67	-	0.01 and less	-	-	-
	1	76	-	0.05	-	-	-
Georgian SSR, marsh gas	14	75	-	0.01 and less	-	-	-
	1	-	-	-	-	less than 0.001	-
Georgian SSR gas from buried peat	1	-	-	0.002	-	-	-
Kerchen peninsula marsh gas	2	65	-	less than 0.01	-	-	-
Bashkiria, marsh gas	164	-	-	0.01 and less	-	-	-
	12	-	-	0.02-0.11	-	-	-
	2	-	-	0.1 -0.3	-	-	-
Black Sea coast isl. Paleostom	6	42	-	-	-	less than 0.002	-
Caspian Sea, marine ooze	15	-	0.005-0.01	-	-	-	less than 0.001

with oil-sorption phenomena and surface properties of rock particles. Were a small part of the organic substance coverted to oil and gas it should be borne in mind that under the influence of certain factors, the first stage of their migration must be oil and gas desorption from organic oil-mother substances. Few difficulties arise in hydrocarbon-gas (methane, ethane) migration; these gases are barely sorbed by organic matter. Diffusion of the gas formed allows it to shift from organic substances fo surrounding water or free pores. Liquid-hydrocarbon desorption is more difficult and requires considerable temperature increase. This desorption and further oil migration in the gaseous phase owing to the reverse phenomenon is facilitated by gaseous hydrocarbons under high pressure. Possibilities of desorption and further migration already are very limited with respect to resinous substances and high-molecular-weight hydrocarbons.

Gas accumulation also may be the result of squeezing from argillaceous rock, of water saturated with dissolved gas. Separation of dissolved gas from water in porous beds, where pressure is lower than that of clay formations, also may lead to its accumulation in traps. The squeezing of liquid oil in small amounts from clay formations containing only a small percentage of such oils, is extremely difficult or even impossible because of its sorption (especially that of heaviest oil components) by organic substances or by rock-particle surfaces.

Dispersed-oil migration and accumulation in porous and fissured rocks may be connected with water displacement and with oil transport and buoyancy. Differences in rock permeabilities with respect to water and oil, flexures of bedding layers, and other conditions facilitate oil accumulation. The assumption that dispersed C_{14} - C_{30} hydrocarbons present in young sedimentary deposits either will form an oil deposit after their accumulation, or will represent an intermediate product, cannot be considered correct in view of migration and accumulation phenomena. Concentration of these hydrocarbons is very low in organic substances; migration and accumulation is impeded by sorption both by organic substances and rocks.

Conditions prevailing in young sedimentary deposits are extremely unfavorable for oil migration. Sorption of liquid hydrocarbons by organic substances and rock particles is favored under low temperatures in young sedimentary deposits.

We may come, then, to the conclusion that oil-formation and accumulation processes occur only at great depths; i. e., below 1 to 2 km.

CHANGES IN CHEMICAL COMPOSITION, CONCENTRATION, AND pH OF GASEOUS-LIQUID INCLUSIONS IN SUCCESSIVE FLUORSPAR SERIES[1]

by

G. G. Grushkin and P. L. Prikhidko

• *translated by V. P. Sokoloff* •

ABSTRACT

Three principal generations of fluorspar (dark violet, violet, and green) are discussed as part of a study on hypogene vein minerals. Spectrographic analysis revealed foreign chemical admixtures, apparently included in fluorspar as it replaced limestone. Occurrence of small quantities of admixtures in later generations agreed with distribution of fluorspar generations in the ore body. Gaseous-liquid inclusions containing alkalies and other solutes, were studied microchemically and spectrographically: To determine efficiency of the extraction method, parallel analyses were conducted comparing prolonged- to rapid-leaching processes. SiO_2, CO_3, NO_3, SO_4, R_2O_3, and Fe^{2+} were absent in the aqueous extractions; Cl, K, Na, and Mg (removed during the first extraction-leaching) generally were absent in later extractions. F, Ca, and HCO_3 were determined by the difference between basic- and control-analysis data. Spectrographic analysis of control specimens was used to ascertain whether extracted salts were present in mineral inclusions: Alkali content of various samples correlated directly with content of included material demonstrating that alkalies were contained in the inclusions; i. e., not atomically interspersed in the crystal structure. Weight loss in fluorspar, measured by heating and thus exploding inclusions, was greatest between 200 and 400°C; beyond 400° C no further weight loss occurred. Analysis indicated that fluorspar-forming solutions changed gradually from alkali-chloride and -fluoride to sodium and calcium bicarbonate in composition, accompanied by increase in pH. Discovery, by one of the authors, that gaseous-liquid inclusions obey van der Waals' law, made it possible to determine their composition; consequently, it was possible to group certain types of inclusions, previously considered impossible to subject to combined analysis, under a single category. --D. D. Fisher.

This report is a continuation of our studies of hypogene vein minerals at the site already discussed by one of the authors in several publications (Grushkin [3], Grushkin and Khelvas [4], Yermakov [5]). We are presenting here our first results on the chemical composition of the inclusions. The data do not take into account volatile gases such as CO_2, which, in certain quantities, were probably present in the inclusions, but during pulverization of the samples prior to the extraction of salts, were volatilized. In addition, we did not consider solubility of the host mineral at temperatures and pressures representing inclusion homogenization environments. The possibility that some elements may have entered into the solute from sources other than the inclusions, e. g., from very large pulverized mineral surfaces, may not be disregarded entirely; although the spectrographic analyses (table 5) show the proportions of such admixtures, with respect to the included salts, to be so small that, for all practical purposes they are undetectable. These corrections, to be made eventually, will result in substantially greater degree of accuracy for our data; in all probability, however, our basic conclusions regarding the course of the process will remain valid.

In the present investigation, three principal generations of fluorspar were used according to the crystallization sequence: dark-violet, violet, and green. Complete chemical analyses of these fluorspars are shown in Table 1, and

TABLE 1. Chemical analysis of three fluorspar generations

Constitutent	Dark-violet	Violet	Green
	%	%	%
Ca	50. 60	51. 04	51. 44
F	46. 70	46. 30	46. 76
SiO_2	0. 78	0. 56	0. 32
Al_2O_3	0. 07	0. 34	0. 44
Fe_2O_3	0. 49	0. 01	0. 26
FeO	0. 20	0. 14	0. 09
MgO	0. 18	0. 14	0. 13
Na_2O	0. 76	0. 58	0. 17
K_2O	0. 15	0. 08	0. 05
S	0. 03	0. 02	0. 02
SO_3	0. 01	0. 02	0. 02
H_2O (105°)	0. 05	0. 04	0. 03
Loss on ignition	0. 37	0. 57	0. 34
Total	100. 36	99. 80	100. 09

were done by E. Semenova, Analyst, at the Institute of Geology Chemical Laboratory, Academy of Sciences, Uzbek, S. S. R.

From the analytical data it is evident that pure crystalline fluorspar contains various types of admixtures; these admixtures do not have the same origin. It was found that SiO_2 and Al_2O_3 are not constitutional admixtures;

[1]Translated from Ob izmenenii Rhimicheskogo sostava, Kontsentratsii i pH gazovo-zhidkikh v klyucheny v ryade posledovatelnykh generatsy flyuorita: Zapiski Vsesoyuznogo Mineralogicheskogo Obschestva, Ch. LXXXI, no. 2, 1952, p. 120-126.

rather, they are derived from silica and clay particles captured by the fluorspar from limestone during replacement. Presence of silica, moreover, may result from fluorspar replacement by quartz; and presence of alumina, kaolin admixtures that had crystallized in fluorspar. Ferric iron may be caused by ferrugination of fluorspar, along the tiniest cracks, following oxidation of pyrite. Divalent iron and sulfur appear to result from pyrite and chalcopyrite admixtures. We attribute alkali content and loss on ignition to gaseous-liquid substance included in the mineral.

To control test for these and other generations of fluorspar, lumps of pure fluorspar to be used in spectrographic analysis, were cut out of the crystals. The analyses were performed in a quartz spectrograph, at the Institute of Geology Spectrographic Laboratory, Academy of Sciences, Uzbek S. S. R.; the results are presented in Table 2.

An aliquot of pure fluorspar from a strictly defined generation containing inclusions of one single genetic type peculiar to the growth of a particular mineral layer, was pulverized to 0.01 to 0.001 millimeter (mm) fineness; to assure mechanical crushing and exposure of practically all of the inclusions in the samples, an agate mortar was used. Solutes of the inclusions were extracted by distilled water, inasmuch as they are solutes of aqueous solutions. Each of the analyses was run under two parallel controls: The first control was introduced to ascertain the correction for solubility of the host mineral. This was done after the first extraction of the sample, by repeating the entire extraction procedure. [Tr.: e.g., by simple re-extraction of the already pulverized and extracted material. VPS]. The second control, a blank, was introduced to make the required corrections for water, reagents, and glassware used in the analysis; all of these determinations were made concomitantly.

TABLE 2. Spectrographic analysis of several fluorspar generations

Fluorspar generation	Na	Mg	Al	Si	Mn
Dark-violet	10^{-2} - 10^{-4}	10^{-2} - 10^{-3}	1.0 - 10^{-2}	1.0 - 10^{-1}	None
Violet	10^{-2} - 10^{-4}	10^{-2} - 10^{-3}	1.0 - 10^{-2}	1.0 - 10^{-1}	10^{-3} - 10^{-4}
Transparent	10^{-2} - 10^{-4}	10^{-3} - 10^{-4}	1.0 - 10^{-2}	10^{-1} - 10^{-2}	None
Green	10^{-2} - 10^{-4}	10^{-3} - 10^{-4}	10^{-2} - 10^{-3}	10^{-1} - 10^{-2}	10^{-3} - 10^{-4}
Pink	10^{-2} - 10^{-4}	10^{-3} - 10^{-4}	10^{-2} - 10^{-3}	10^{-1} - 10^{-2}	None

Note: Analyses by I. I. Islamova.

These studies showed the quantities of magnesium, alumina, and silica admixtures to be smaller in the later fluorspar generations. The previously cited chemical analysis for silica and magnesium was confirmed by the spectrographic analysis. The relationships in question are in accord with the distribution of fluorspar generations in interformational ore deposits of the ore-body. The earliest generations, the dark-violet and violet fluorspar, generally were laid down adjacent to the shaly hanging wall of the ore body; there, they replaced the not-so-pure transitional varieties of limestone containing more or less appreciable amounts of siliceous and clayey particles; subsequent fluorspar generations were replacing purer limestone. In this paper we have not reported the limestone-profile chemical analyses which had confirmed these relationships. Among the 36 elements sought in the fluorspars, only those reported here were detected. I. P. Alimarin [1] had found Na, Li, Sr, Fe, Mn, and Cu in admixtures to fluorspars from the same deposit.

Chemical admixtures of alkalies and other solutes from gaseous-liquid inclusions in the fluorspars, were studied microchemically and spectrographically.

We employed the following microchemical analytical procedures to the fluorspar inclusions:

Extraction efficiency was tested experimentally, by comparison of prolonged- to rapid-leaching processes. Two aliquots of the same sample were treated by different methods: The first, 800 grams (g), was extracted four times in succession by distilled water. One liter (L) of water was used for each extraction; in each case, duration of contact was 4 days. The water-powder mixture was shaken periodically. Total duration of the extraction was 16 days; total volume of leached material was brought to 4 liters. The second aliquot of 700 g, prepared as described previously, was covered by 1 L of water, shaken continuously for 20 minutes, filtered on the Büchner funnel, and leached for 1 hour. Combined volume of material leached and washings was 1.4 L. The entire procedure took 1 hour 20 minutes; data are given in Table 3.

Orders of magnitude of the figures reported in Table 3 is approximately the same for the parallel tests; therefore, we find that use of the short-time extraction in our further work is justifiable. Constituents of the aqueous extracts were determined here, as well as in the previously reported analyses, by the following microchemical procedures (anions were determined volumetrically and colorimetrically; cations, gravimetrically):

Cl - volumetrically, according to Mohr;

F - colorimetrically, by sodium alizarine sulfoxyl [Ed.: sulfonate (?) MF];
HCO_3 - volumetrically, with methyl orange;
Ca - gravimetrically, by the oxalate method;
Mg - by the pyrophosphate method;
K - gravimetrically, by the chloroplatinate method: by weighing metallic Pt after reduction of the chloroplatinate;
Na - gravimetrically, by difference from the sum of the chlorides. [Tr.: Probably by weighing KCl + NaCl and substracting potassium chloride (KCl) from the total, etc.

TABLE 3. Data on comparison of prolonged and rapid leaching processes (conducted as a test of extraction efficiency)

Constituent	Extraction	
	16 days	1 hr. 20 min.
	Percent of original sample	
Cl	0.0067	0.0059
HCO_3	0.0009	0.0012
Total anions	0.0076	0.0071
K	0.0005	0.0005
Na	0.0034	0.0031
Mg	0.0006	0.0004
Total cations	0.0045	0.0040
Total anions plus cations	0.0121*	0.0111
Dry residue	0.0131	0.0121

* 0.0120 in original.

For the three samples presently to be discussed, volumes of aqueous extracts used in each analysis represented 100, 200 and 150 g [Ed.: 250(?)] of the original sample, respectively. For the sake of uniformity, all calculations in the following comparison (table 4) are reduced to a basis of 100 g.

In addition, the following constituents were tested for, and were proved to be absent, in the aqueous extracts: SiO_2, CO_3, NO_3, SO_4, R_2O_3, and Fe^{2+}. Comparisons between basic, control, and blank tests were helpful in determining certain differences in the behavior of certain constituents during extraction. Cl, K, Na, Mg, were extracted quantitatively during the first extraction-leaching; as a rule, they were absent in subsequent extracts; or, in one or two instances, were observed as indefinite traces. F, Ca, and HCO_3 were determined by difference between basic- and control-test analyses. Repeated control extractions were performed to determine solubility of CaF_2. Because in the first extracts Ca and F were invariably higher than in the controls, the difference was attributed to presence of these ions among the salts, i.e., solutes of the liquid phase of inclusions, that during the extraction-leaching operations, passed from inclusions into the extracts.

Microchemical analysis results are presented in Table 4.

TABLE 4. Microchemical analysis data for three fluorspar generations

Constitutent	Fluorspar generation					
	Dark-violet		Violet		Green	
	% in 100 g of original sample	g/eq	% in 100 g of original sample	g/eq	% in 100 g of original sample	g/eq
Cl	0.0025	0.0705	0.0067	0.1899	0.0003	0.0084
F	0.0002	0.0105	0.0002	0.0105	0.0001	0.0052
HCO_3	-	-	0.0007	0.0115	0.0022	0.0360
Total anions	0.0027	0.0810	0.0076	0.2109	0.0026	0.0496
K	0.0011	0.0282	0.0004	0.0102	0.0001	0.0026
Na	0.0010	0.0432	0.0034	0.1479	0.0005	0.0217
Ca	0.0002	0.0097	0.0004	0.0194	0.0005	0.0242
Mg	-	-	0.0004	0.0328	-	-
Total cations	0.0023	0.0811	0.0046	0.2103	0.0011	0.0485
Total anions + cations	0.0050	0.1621	0.0122	0.4212	0.0037	0.0981
Total salts, anions + cations	0.0050	-	0.0119	-	0.0026	-
Dissolved CaF_2	0.0029	-	0.0030	-	0.0029	-
Total salts	0.0079	-	0.0149	-	0.0055	-
Dry residue	0.0086	-	0.0153	-	0.0059	-

Probable composition of salts (grams per 100 grams sample)
[Based on data in Table 4, preceding page]

Salt	Dark-Violet	Violet	Green
KCl	0. 00210	0. 00076	0. 00024
NaCl	0. 00192	0. 00804	0. 00027
NaF	0. 00044	0. 00044	0. 00022
$MgCl_2$	-	0. 00156	-
$CaCl_2$	0. 00054	0. 00046	-
$Ca(HCO_3)_2$	-	0. 00094	0. 00198
$NaHCO_3$	-	-	0. 00099
Total	0. 00500	0. 01220	0. 00370
pH	7. 0	7. 3	7. 6
Sample weight (g)	600	800	900
Water volume (L)	1. 2	1. 6	1. 8

Probable composition of the extracted salts was estimated by matching equivalent combining weights of the constituents, in the following sequence:

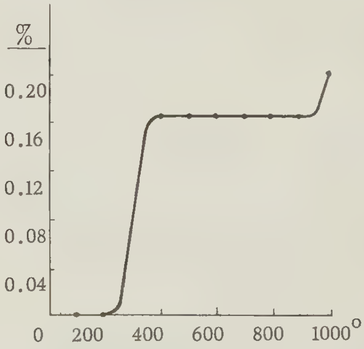
Dark-Violet	Violet	Green
Ca + Cl F + Na Na + Cl Cl + K	F + Na Na + Cl K + Cl Cl + Mg HCO_3 + Ca Ca + Cl	Ca + HCO_3 HCO_3 + Na F + Na Na + Cl K + Cl

Fluorspars with and without inclusions, powdered and leached fluorspars, and ignited fluorspars were examined spectrographically, to ascertain that the extracted salts were indeed present in mineral inclusions. Results of quintuplicate, precision spectrographic analyses for alkali and alkaline earth elements are presented in Table 5; the analyses were carried out at the Physics-Technical Institute Spectrographic Laboratory, Academy of Sciences, Uzbek S. S. R.

approximate 10-fold decrease in the quantity of alkalies; 3) Alkalies are removed almost entirely from powdered fluorspar by the aqueous extraction. If the alkalies were present as atomically dispersed admixtures, in the fluorspar crystal structure, they could not be extracted by water or lost by ignition. Thus, we may conclude that alkalies are present, in the mineral discussed here, as solutes in the liquid phase of gaseous-liquid inclusions.

By way of proof that all loss on ignition at 800°C resulted from presence of water in gaseous-liquid inclusions, and to determine absolute quantities of this water, we used the following procedure.

It is well known that gaseous-liquid inclusions explode on overheating. During the heating of the sections (in a thermostat of 200 to 400°C, the explosions are visible to the unaided eye; they are accompanied by crackling which is easily audible without the amplifier. Further application of heat causes no further explosions. Examination of sections heated to 400 to 500°C showed absence of any unexploded inclusions in the specimens.



t °C	Loss of H_2O %
0	0.000
100	0.000
200	0.000
300	0.087
400	0.167
500	0.168
600	0.168
700	0.168
800	0.168
900	0.168
1000	0.203

FIGURE 1. Weight loss on ignition of fluorspar

TABLE 5. Spectrographic analyses for alkali and alkaline earth elements (quintuplicate determinations)

Specimen and Material	K (%)	Na (%)	Mg (%)
1. Violet fluorspar without microscopically visible inclusions	10^{-5} - 10^{-6}	10^{-4} - 10^{-5}	10^{-3} - 10^{-4}
2. Violet fluorspar with inclusion	10^{-4} - 10^{-5}	10^{-2} - 10^{-4}	10^{-3} - 10^{-4}
2. Violet fluorspar with inclusion; ignited at 1200°C	10^{-5} - 10^{-6}	10^{-4} - 10^{-5}	10^{-4} - 10^{-5}
2. Violet fluorspar with inclusion; pulverized to 0. 01 - 0. 0001 mm size; after aq. [Ed. : aqueous (?)] extraction	trace, or absent	trace, or absent	10^{-4} - 10^{-5}

From Table 5 it is obvious that:
1) In fluorspar containing no visible inclusions, quantities of alkalies were 10 times less than in fluorspar of the same generation containing visible inclusions; 2) Ignition of the same sample to 1, 200°C, also resulted in an

Concurrent with the visual observations, we were observing weight losses, recorded every 100°C, of fluorspar lumps in five covered platinum crucibles. The curve (fig. 1), represents the arithmetic mean of losses on ignition; it is apparent that most losses take place

between 200 and 400°C. Characteristically, weight loss within this range also accompanied by audible crackling, results from explosions of inclusions; this is entirely in line with our visual observations. No weight losses whatsoever occur in the 400 to 800°C range.

Several experiments of the following types served as controls: 100 g aliquot of fluorspar lumps dried at 150°C, was placed in a quartz flask with a condenser and heated to 700° - 750°C; during heating, the inclusions exploded. Differences between the weight loss of fluorspar and the weight of water trapped in the condenser, were within the fourth significant figure; i. e., approximately 1 percent of the total, 0.1209 as against 0.1198, etc. [Tr.: Or, rather, within the first three significant figures. VPS].

For each variety of fluorspar, averages of the quintuplicate determinations, taken in the quartz flask with the condenser as described here, are given in Table 6 as g/100 g of the original samples.

TABLE 6. Averages of quintuplicate determinations for three fluorspar generations

Fluorspar generation	g/100 g of sample		Concentration %
	Water in inclusions	Salts	
Dark-violet	0.0421	0.0500	11.88
Violet	0.1233	0.0122	9.88
Green	0.0650	0.0037	5.69

Effects on specific gravity of the mineral caused by presence of the inclusions were ascertained in a parallel study:

Violet fluorspar with inclusions: 3.151; same, ignited to 700°C: 3.156; according to text violet fluorspar without visible inclusions: 3.157; same, ignited to 700°C: 3.157.

Specific gravity decrease was 0.005 in the first case, corresponding to 0.159 percent. We may note that this figure closely approximates 0.168 percent, i. e., the weight loss per 100 g of the original sample; a result of water evaporation on dehydration of the fluorspar (see fig. 1).

The analyses showed composition of fluorspar-forming solutions to change in an orderly manner from the alkali chlorides and fluorides to bicarbonates of sodium and calcium; the change is accompanied by increase in pH of the solution. All these changes in hydrothermal minerals composition depend chiefly on environment: As they replace ore-bearing limestone, the fluorine compounds are liberating appreciable quantities of calcium and CO_2; part of this calcium is bound as fluorspar, and part enters the solution as bicarbonate. Hence, pH of the solution, increases from neutral to weakly alkaline (table 5).

Crystallization of fluorspar is accompanied by continuous decrease in total dissolved-salt concentration (table 6). Decreasing concentration of sodium fluoride and rising concentration of bicarbonate are especially characteristic during the process. The analyses cited here do not take into account corrections for true concentrations of calcium and fluorine; because of fluorspar solubility, at different temperatures, pressures, and compositions of the solutions, representing homogenization of the gaseous and liquid phases of inclusions belonging to different generations.

The reader is referred to the reports by G. G. Lemmleyn[6] and N. P. Yermakov [5] for data on solubility of minerals containing inclusions.

Analysis of inclusion composition was made possible only after discovery by one of the authors, that gaseous-liquid inclusions obey the van der Waals' law. This observation permitted us to combine several types of inclusions into a single category; these inclusions were considered in the literature to be of the same type but they differed among themselves so strikingly in their formation environments, that their combined analysis was considered impossible. The authors plan to publish the additional details as a separate note.

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GEOCHEMISTRY OF RARE EARTH ELEMENTS[1]

by

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• *translated by Research International* •

ABSTRACT

Although called rare earths, elements lanthanum (atomic number 57) through lutetium (atomic number 71) on the periodic table, including yttrium (atomic number 37), are more common in nature than are many of the industrially important nonferrous metals. The rare-earth elements occur in oxide, silicate, phosphate, and carbonate compounds or as small fractions replacing calcium and strontium, whose ionic radii are similar to those of the rare-earth elements. Rare-earth minerals are more commonly found in pegmatites, granites, and nepheline syenites. Further study of the rare earths will aid geochemical prospecting, determination of mineralization processes, and clarification of geologic processes, as well as augmentation of alloy-metal reserves and product differentiation. --Research International.

Rare-earth elements are those elements which, in D. I. Mendeleyev's period system, number from 57 (lanthanum) to 71 (lutetium), inclusively. They are also known as lanthanides; yttrium has been added to their number (table 1).

The name "rare-earth" is obsolete; some of these elements occur more commonly and in greater amounts than well-known elements which play a significant role in technology. For instance, the cerium, neodymium, and yttrium content of the earth's crust is greater than that of beryllium, arsenic, niobium, molybdenum, silver, antimony, lead, gold, platinum, and others.

The first rare-earth elements were discovered in 1794 by the Finnish chemist J. Gadolin during analysis of a mineral now called gadolinite. In 1797, Swedish chemists called these elements yttria earths. In 1803, rare-earth elements were discovered simultaneously by a German chemist M. Klaprot and by a Swedish chemist J. Berzelius in the mineral cerite. The first division of the rare-earth elements into two groups, the yttrium and cerium groups, was proposed by Berzelius and Gan in 1814.

Lanthanum, cerium, praseodymium, neodymium, promethium, samarium, and europium comprise the cerium group; gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, and yttrium comprise the yttrium group.

The rare-earth elements have been the object of study by many investigators because these elements are of considerable practical, as well as scientific, interest.

The extraction of rare earths has increased considerably during the past several years. For the period from 1930 to 1939, an average of 4,500 tons per year was mined abroad; while, in 1955, 32,000 tons were mined. Their use has become extremely diversified [11]. Moreover, until recently, only mixtures of rare earths were produced in considerable quantities; now large-scale production of individual elements has been achieved and the use of some of them in industry has increased significantly.

The rare earths are used in metallurgy as alloys for various types of steel. In the metallurgy of nonferrous metals, rare earths are also used to improve the quality of various alloys, particularly aluminum and manganese.

Rare-earth elements are gas absorbents which are used in the production of electron tubes (vacuum tubes) and crystalline phosphates (television tubes); they are used in electron-beam tubes (radiation-detection instruments), and in other devices. In atomic technology, some of these elements are used as neutron absorbents in reactors and as gamma sources. For instance, after irradiation in a nuclear reactor, thulium-169 produces thulium-170 which is a source of soft gamma emission. This process replaces contemporary X-ray installations. Such a gamma source is portable, does not require electric power, and can be operated under any conditions. This gamma-emittor is also used in defectoscopy. Rare-earth elements are also used in electrotechnology, in the preparation of carbon electrodes for arc lamps and projectors which result in maximum illumination; in the chemical industry, as catalysts in the production of artificial fabrics, plastics, oil-cracking materials; in light industry, as dye for leather and textiles, impregnation of textiles and textile weaving; in the silicate industry, for the production of glass which will transmit infrared rays but which will absorb ultraviolet

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[1]Translated from Geokhimiya redkozemelnykh elementov: Priroda, no. 6, p. 19-26, 1959.

[2]V. I. Vernadsky Institute of Geochemistry, Academy of Sciences, U.S.S.R. (Moscow).

rays, as a coloring and decolorizing agent, as a polish for optical glass; and in many other facets of the national economy. Rare-earth elements are also very important as tools in solving geochemical problems.

The Russian scientist, A. Ye. Fersman, and the Norwegian scientist, V. M. Goldschmidt, have made significant contributions to the study of rare-earth elements. Comparative contents of the rare-earth elements in the earth's crust (table 1, fig. 1) indicate that, for two consecutive elements in the Mendeleyev table, those with even atomic numbers are found in greater quantities than those with odd atomic numbers. This geochemical peculiarity has been repeatedly noted by Goldschmidt and other investigators.

The rare-earth elements from lanthanum (57) to lutetium (71), including yttrium (39), are typically found together in the same minerals. This can be explained by the particular electronic structures of the rare earths. As the consecutive elements increase in atomic number and,

TABLE 1. Rare-earth elements and their content in the earth's crust

Atomic number	Element	Symbol	Valence	Ionic radius (trivalent) (Å)	Content in earth's crust (grams per ton)		
					Fersman	Vinogradov	Goldschmidt
39	Yttrium	Y	3	1.06	50	28	31
57	Lanthanum	La	3	1.22	6.5	18	19
58	Cerium	Ce	3,4	1.18	29	45	44
59	Praseodymium	Pr	3, (4)	1.16	4.5	7	5.6
60	Neodymium	Nd	3	1.15	17	25	24
61	Promethium	Pm	3	-	?	?	?
62	Samarium	Sm	(2), 3	1.13	7	7	6.5
63	Europium	Eu	2, 3	1.12	0.2	1.2	1
64	Gadolinium	Gd	3	1.11	7.5	10	6.3
65	Terbium	Tb	3, (4)	1.09	1	1.5	1
66	Dysprosium	Dy	3	1.07	7.5	4.5	4.3
67	Holmium	Ho	3	1.05	1	1.3	1.2
68	Erbium	Er	3	1.03	6.5	4	2.4
69	Thulium	Tm	3	1.01	1	0.8	0.3
70	Ytterbium	Yb	(2), 3	1.00	8	3	2.6
71	Lutetium	Lu	4	0.99	1.7	1	0.7

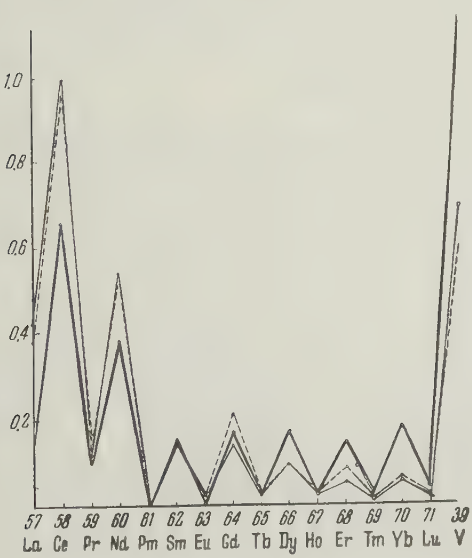

FIGURE 1. Relative content of rare-earth elements in the earth's crust, according to data from A. Ye. Fersman.

consequently, as their nuclear charge increases, new electrons enter one of the inner shells, while the number of electrons in the outer shells remains the same. The similarity of the distribution of electrons in the outer shells of the rare earths explains their exceptional similarity in chemical properties and their close association in nature.

In nature compounds (minerals), rare-earth elements have valences of three, or more rarely, two or four. A valence of four is most characteristic for cerium. Only europium is naturally bivalent. Europium is concentrated in minerals containing potassium, strontium, and lead, namely in feldspars, sphene, strontianite, and pyromorphite [6]. Europium occurs in considerably smaller concentrations in rare-earth minerals than do the other odd-numbered rare earths, for europium is formed in nature not only in the trivalent state, but also in the bivalent, which causes its isolation from the other lanthanides.

In the earth's crust, rare-earth elements either form separate minerals or enter into the composition of other minerals by replacing with-

in them atoms or ions of elements which are similar in atomic radius, valence, and type of crystalline structure. In many minerals a close relationship between the rare earths and calcium and strontium exists. Calcium and strontrium are frequently replaced by rare-earth elements, as has been observed by Goldschmidt [5] and Fersman [3]. This replacement is particularly well developed in minerals contained in highly alkaline rocks (nepheline syenites). Apatite, loparite, rinkolite, eudyalite, and others serve as examples (table 2). Sodium is also usually contained in these minerals. The replacement of calcium and strontium by rare earths in these minerals can be schematically represented in the following manner:

$$Ce^{3+} + Na^{+} \longrightarrow (Ca, Sr)_2^{2+}.$$

The replacement of bivalent elements, calcium and strontium, by trivalent rare earths is facilitated primarily by the similarity of their ionic radii. The ionic radii for the trivalent elements of the cerium group range from 1.22 Angstroms (Å) for La to 1.12 Å for Eu, and, for the yttrium group, from 1.11 Å for Gd to 0.99 Å for Lu; the ionic radius for Ca^{2+} is 1.06 Å and for Sr^{2+} is 1.27 Å [7].

The relationship between rare-earth elements and thorium, uranium, zirconium, niobium, and tantalum is close in minerals; in the uranium and thorium oxides: uraninite and thorianite; thorium and zirconium silicates: thorite, zircon, and their varieties; rare-earth phosphates: monazite; and in minerals of the titanate-tantalate-niobate group. In minerals of the uranium, thorium, and zirconium oxides and silicates, the rare-earth elements are actually tetravalent and replace uranium, thorium, and zirconium. The ionic radii of these elements in the tetravalent state are very similar: Ce^{4+} = 1.02 Å, Pr^{4+} = 1.00 Å, Tb = 0.89 Å, Th^{4+} = 1.10 Å, U^{4+} = 1.05 Å, and Zr = 0.87 Å.

In monazite ($CePO_4$), a widespread thorium-bearing rare-earth mineral, the rare-earth elements are trivalent and may be replaced by tetravalent thorium, probably in the following way:

$$Th^{4+} + Ca^{2+} \longrightarrow 2Ce^{3+} \text{ or,}$$
$$Th^{4+} + Si^{4+} \longrightarrow Ce^{3+} + P^{5+}.$$

In the minerals of the titanate-tantalate-niobate group (fergusonite, euxenite, polycrase-eschynite, samarskite, and others), the rare-earth content ranges from several dozen percent to 41 percent. Minerals composed entirely of rare earths, or minerals with admixtures of rare earths, occur in this group. They apparently replace calcium in the following way:

$$Y^{3+} + Ti^{4+} \longrightarrow Ca^{2+} + Nb^{5+}.$$

In the titanate-tantalate-niobate minerals, the rare-earth elements are, in the majority of cases, composed of the yttrium group.

The concentration of bivalent europium in minerals containing potassium, strontium, and lead, is explained by the similarity of their ionic radii: Eu^{2+} = 1.24 Å, Sr^{2+} = 1.27 Å, Pb^{2+} = 1.32 Å, and K^{+} = 1.33 Å.

Minerals containing rare-earth elements are usually divided into two groups, as proposed by Goldschmidt and Tomassen [9]: 1) complex minerals containing a number of rare-earth elements without either of the cerium or yttrium groups predominating, as in fluorite, gadolinite, and pyrochlore; 2) selective minerals in which either the cerium group (monazite) or the yttrium group (xenotime) predominate. E. I. Semenov [14] has distinguished mineral groups on the basis of predominating cerium, neodymium, gadolinium, and yttrium.

Certain definite relationships and uniformities exist between the rare-earth elements in minerals. Thus, from the ratio of cerium to neodymium in selective cerium minerals; from yttrium to erbium in selective yttrium minerals; from cerium, ytterbium, and erbium to neodymium in complex minerals, the relationships between all rare-earth elements in minerals can be determined. Uniformities in the distribution of atoms of rare-earth elements have also been noted. Within the lattice, rare-earth elements have coordinated numbers from 6 to 12 [14], and the high coordination numbers, 10, 11, 12, are characteristic for the selective cerium minerals; the low number, 6, for selective yttrium; and the intermediate numbers, 7, 8, 9, for complex rare-earth minerals and, more rarely, selective yttrium minerals. The coordination number of one ion (atom) is the number of ions (atoms) of another element adjacent to it; the same pattern is repeated throughout the crystal lattice.

Minerals containing rare-earth elements are referred to the following groups (table 2): halogen compounds, 3 minerals; oxides (basically complex Ti, Nb, and Ta oxides), more than 40 minerals; carbonates, 11 minerals; phosphates, 12 minerals; and silicates, 33 minerals.

The majority of rare-earth minerals have been found in pegmatites. Pegmatites are coarse-grained rocks, formed from the final magmatic melt; they are enriched with volatiles (water, fluorine, chlorine, and others), and rare and scattered elements (niobium, lithium, beryllium, and others). They are genetically related to granites and nepheline syenites. In granitic pegmatites, the yttrium group of rare earths usually predominates; in the nepheline syenites, the cerium group usually predominates.

In granitic pegmatites, the primary rare-earth minerals are related to complex oxides containing Ti, Nb, Ta, frequently Th, U, and

TABLE 2. Major rare-earth minerals

Mineral	Formula	Content (%)			Type deposit
		Ce_2O_3	Y_2O_3	TR_2O_3	
Complex oxides					
Knopite	$(Ca, Ce)(Ti, Fe)O_3$	6.81	-	-	Contact-metamorphic-magmatic
Loparite	$(Na, Ce, Ca)(Ti, Nb)O_3$	31-33	-	-	Magmatic
Pyrochlore	$NaCaNb_2O_6$	4.36-5.90	0.46	4.36-6.36	Pegmatitic
Fergusonite	$(Y, Er, Ce)(Nb, Ta)O_4$	0.2-4.0	28-40	31-41	Pegmatitic (granite)
Euxenite	$(Y, Ca, Ce, U, Th)(Nb, Ta, Ti)_2O_6$	0.4-2.4	24-28	25-30	Pegmatitic (granite)
Polycrase	$(Y, Ca, Ce, U, Th)(Ti, Nb, Ta)_2O_6$	0.6-2.6	25-27	26-29	Pegmatitic (granite)
Eschynite	$(Ce, Ca, Fe^{2+}, Th)(Ti, Nb)_2O_6$	19.50	4.53	25.0	Pegmatitic (nepheline syenite)
Priorite	$(Y, Er, Ce, Ca, Fe^{2+}, Th)(Ti, Nb)_2O_6$	2-4.3	17-29	21-30	Pegmatitic (granite)
Samarskite	$(Y, Ce, U^{4+}, Fe^{2+})(Nb, Ta)_2O_6$	0.9-4.2	8-17	10-19	Pegmatitic (granite)
Chlopinite	$(Y, U, Fe)(Nb, Ta, Ti)_2O_6$	-	17.65	-	Pegmatitic (granite)
Brannerite	$(U, Ca, Fe)TiO_6$	0.3-7.3	1.8-4.3	to 7.35	Pegmatitic-contact metasomatic
Simple oxides					
Uraninite	$1(U, Th)O_2 \cdot mUO_3 \cdot nPBO$	-	-	to 4.4	Pegmatitic (granite)
Bröggerite	(var. of uraninite $-TiO_2$	-	-	to 6.16	
Cleveite	(var. of uraninite -Tr, Th	-	-	to 15.0	
Thorianite	$(Th, U)O_2 \cdot PbO$	to 8.04	-	to 8.04	Magmatic contact-metasomatic, auriferous
Carbonates					
Parisite	$(Ce, La)_2Ca(CO_3)_3F_2$	55-61	0.0-7.86	5.5-61.0	Pegmatitic, hydrothermal
Bastnäsite	$(Ce, La)(CO_3)F$	73-76	-	-	Contact metasomatic, hydrothermal
Phosphates					
Xenotime	YPO_4	0.9-2.1	57-68	57-68	Pegmatitic (granite)
Monazite	$(Ce, La, Y, Th)PO_4$	52-74	1.1-5.0	56-75	Sand concentrates
Apatite	$(Ca, Ce)_5(PO_4)_3(F, Ce, OH)$	0.7-4.9	-	-	Magmatic (nepheline syenite)
Silicates					
Yttrialite	$(Y, Th, U, Fe_2Si_2O_7$	3.8-8.2	43.4-49.3	49-51	Pegmatitic (granite)
Orthite	$(Ca, Ce)_2(Al, Fe)_3Si_3O_{12}(OH)$	11-22.5	0.1-6.1	11-23.3	Magmatic, pegmatitic (granite)
Cyrtolite	$ZrSiO_4 \cdot nH_2O$ (var. of zircon)	to 1.16	to 8.93	to 10.1	Pegmatitic
Rinkolite	$Na_2Ca_4Ce\,Ti(Si_4O_{15})(F, OH)_3$	13.7-14.4	0.9-1.8	15.5-19.1	Pegmatitic (nepheline syenite
Gadolinite	$Y_2FeBe_2Si_2O_{10}$	5-32	22-50	-	Pegmatitic (granite)
Eudyalite	$Na_3Ca\,Fe_2ZrSi_6O_{18}(OH, Cl)$	to 4.26	-	-	Magmatic, pegmatitic (nepheline syenite)

others, as well as some silicates (yttrialite, orthite, cyrtolite, and others) and phosphates (xenotime and monazite). Minerals in which the cerium rare earths sharply predominate over the yttrium group occur among the silicates and phosphates, particularly monazite and orthite. In nepheline-syenite pegmatites, the minerals containing rare earths are most commonly silicates, particularly titanium and zirconium silicates (steenstrupine, rinkolite, lovchorrite, eudyalite, and others).

Pegmatites contain only very small amounts of rare-earth elements; the bulk can be found in magmatic rocks, of which granites and nepheline-syenites are the richest. In the nepheline syenites, the bulk of the rare-earth elements is concentrated in the complex oxide group containing titanium and niobium (loparite), in zirconium and titanium silicates (eudyalite, sphene), and in phosphates (apatite). In these minerals, with the exception of eudyalite, the cerium rare-earth group sharply predominates over the elements in the yttrium group.

The quantitative relationships of the cerium group in minerals which are genetically related to nepheline syenites containing large amounts of potassium and sodium are usually Ce > La > Nd > Pr [2]. Those rare-earth elements which are most strongly alkaline (La and Ce) are concentrated primarily in nepheline syenites which are alkali rich.

In granites, the rare earths are concentrated in orthite, monazite, xenotime, and in minerals containing smaller amounts of rare-earth elements, such as apatite, fluorite, sphene, zircon, garnet, and others.

Little data exists in the geochemical literature on the content of rare-earth elements in rocks; this data, however, is summarized by A. P. Vinogradov [20]. The content of rare-earth elements (with the exception of yttrium) increases from basic to acid rocks. In shales, the average content is 0.015 percent; in deep sediments of the Black Sea, from 0.013 to 0.040 percent; in phosphorites, 0.13 percent, rarely as much as 0.67 percent (1); in soils of the Russian plains, from 0.01 to 0.02 percent; and in the soils of the United States, 0.024 per-

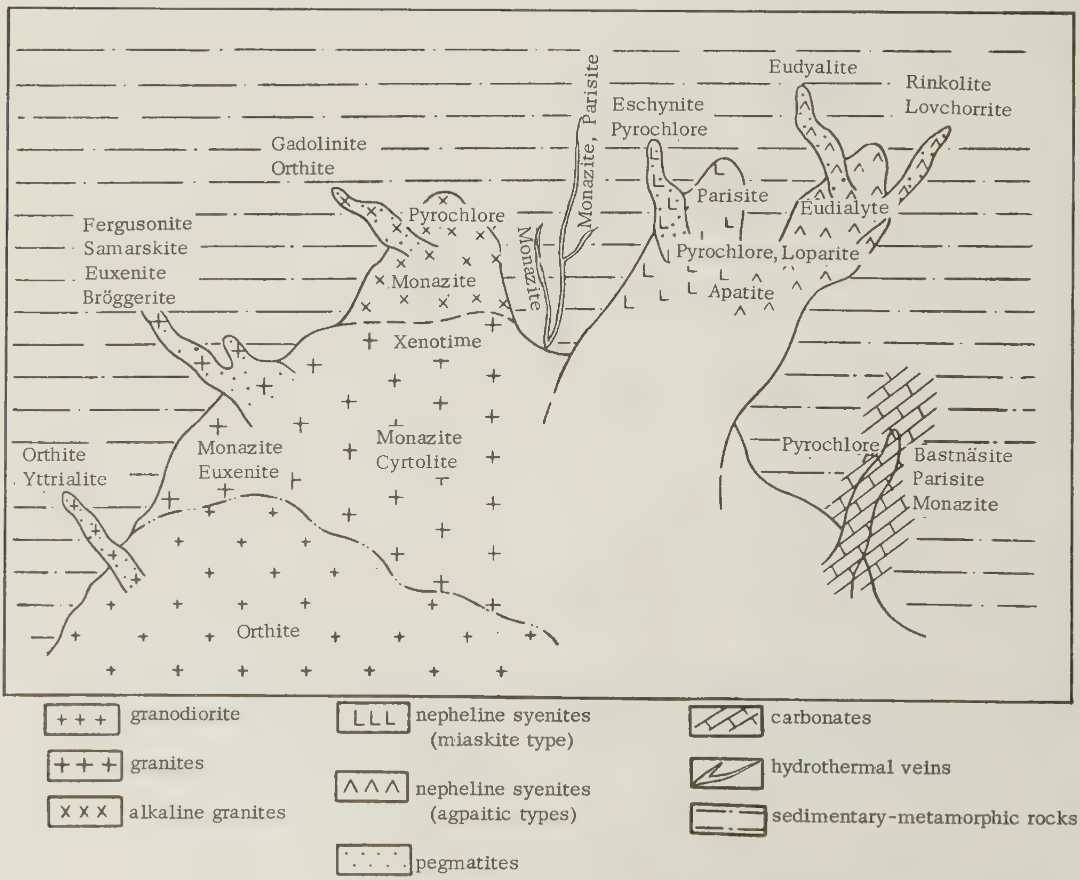

FIGURE 2. A scheme for the distribution of rare-earth minerals in rocks

cent. In sea water, 3×10^{-8} percent lanthanum, 3×10^{-8} percent cerium, and 3×10^{-8} percent yttrium were found; moreover, neodymium, praseodymium, and samarium were quantitatively determined. These were also found in calcareous algae in quantities as great as 5×10^{-6} percent [18]. Rare earths (thousands, hundreds, and even tens of a percent) have been found in coal ash. The average rare-earth element content for sedimentary rocks, clays and shales [19] is: 4×10^{-3} percent La, 3×10^{-3} percent Ce, 5×10^{-4} percent Pr, 1.8×10^{-3} percent Nd, 5×10^{-4} percent Sm, 1×10^{-4} percent Eu, 5×10^{-4} percent Gd, 9×10^{-5} percent Tb, 4×10^{-4} percent Dy, 1×10^{-4} percent Ho, 2.5×10^{-4} percent Er, 2×10^{-5} percent Tm, 2.2×10^{-5} percent Lu, and 3.3×10^{-3} Y. Rare-earth elements can be used as indicators of geologic processes. V. I. Vernadsky [17] was the first to note this, indicating that the composition of rare-earth minerals in pegmatitic structures is practically the same as the composition of these same minerals in rocks.

Literature on this problem is very meager, although of great interest. The distribution of the rare-earth elements helps to explain the conditions of mineral formation and to determine the genetic relationships between the various rocks and forms of mineralization. The relationships of the cerium-group rare-earth elements in apatite from basic rocks (Ce > Nd > La > Pr) is different from those in apatite from nepheline syenites (Ce > La > Nd > Pr). In apatite from gabbro, yttrium sharply predominates over lanthanum (5,000 grams per ton Y; 1,000 grams per ton La); in apatite from granodiorite, the lanthanum concentration is greater than that of yttrium (500 to 700 grams per ton Y, 2,000 to 3,000 grams per ton La) [12].

It has been determined that the relationships of rare-earths in monazite from pegmatites of various regions vary. In certain monazites (Ukraine, Yakutia, Korea), the ratios of the rare-earth elements are the same as in granites (Ce > La > Nd > Pr > Sm > Gd) [21]; in others (Brazil and other regions), it differs by a decrease in La and Ce and in a marked increase in Sm and the other rare-earth elements with higher atomic weights. Monazites of hydrothermally altered pegmatites, carbonate, and quartz veins have a higher concentration of lanthanum and a very low samarium content.

Data on the content of rare-earth elements in deposits of commercial minerals is very interesting [10]. In fluorite associated with galena and sphalerite (England), 4×10^{-4} grams (g) Eu per g mineral was found; in fluorite associated with smoky quartz (Switzerland), approximately 10^{-4} g ytterbium were determined. In scheelite from acid pegmatites and terminal granitic solutions, elements of the yttrium group were found: terbium, dysprosium, and erbium; in scheelite from deposits associated with basic rocks, europium and samarium were determined.

A study of the relationships between rare-earth elements in vein and lode deposits is of great interest as a method of investigating conditions of ore deposition. Microparagenesis of these elements serves as a diagnostic indication very characteristic of conditions under which the minerals were formed; this method can be widely used in prospecting and exploratory work.

The basic source of rare-earth elements in monazite, $(Ce, La, Y, Th)PO_4$, in which 52 to 72 percent is $(Ce, La)_2O_3$, 1.15 to 5.08 percent is Y_2O_3, and 6 to 12 percent is ThO_2. Monazite occurs in littoral concentrations in India, Brazil, Ceylon, Australia, and other countries. Alluvial deposits occur in the United States (Idaho, the Carolinas), Malaya, Indonesia; primary deposits are also known. The largest commercial deposits are found in India (particularly in Travancore); the sands here contain from 3 to 10 percent monazite. The total monazite reserves are estimated to be 1 million tons. Brazilian deposits at Bahia, Espiritu-Santo, and Rio-de-Janeiro are second. One of the large primary deposits is located in the Van-Reinsdorf region of Cape Province, Union of South Africa. It consists of quartz-monazite veins.

The largest exporters of monazite were India and Brazil. During the period from 1893 to 1945, 130 thousand tons of monazite concentrates were extracted; 70 thousand tons were exported from Brazil, 52 thousand from India. At present, the United States is the largest producer of monazite.

Bastnäsite is another source for rare-earth elements. It is a cerium-group fluoride-carbonate, $(Ce, La)(CO_3)F$ [16]. It contains 74 to 77 percent $(Ce, La)_2O_3$. The exploited deposits of bastnäsite in the United States are located in Mountain Pass, California, and in Gallinas, New Mexico. In California, the rare-earth deposits (bastnäsite), associated with barium (barite) and thorium (monazite, thorite, and thorogummite) deposits, are distributed over a zone averaging 10 kilometers (km) wide. The zone occurs in Precambrian rocks and is genetically related to igneous rocks. In New Mexico, bastnäsite occurs in fluorite deposits with barite and goethite. Fluorite-bastnasite deposits were formed from hydrothermal solutions related to igneous activity. Commercial deposits are also known in the Belgian Congo. Which minerals abroad constitute the main source for the rare-earth elements of the yttrium group is unknown; no reliable data are found in the literature on this subject.

Prices for monazite sand in the United States range from $0.40 to $1.50 per kilogram. In

March 1955, the price of 1 kilogram of metallic Ce was $40; for 1 kilogram of lanthanum oxide, $22.

Although a great deal of work has been done on the geochemistry of the rare earths, a great deal has yet to be done. In the future, it will be necessary to pursue further investigations in the following directions:

1. Determination of the total content of rare-earth elements in minerals and rocks and of the quantitative relationships among the individual elements. This is very important also for their industrial utilization.

2. Study of the conditions of migration and concentration of rare-earth elements under various conditions of mineralization (magmatic, pegmatitic, hydrothermal, sedimentary, and others), as well as of the conditions which are favorable for the formation of commercial deposits.

3. Solution of the problem regarding rare-earth elements as indicators of geologic processes. This necessitates a detailed study of the quantitative relationships between rare-earth elements and minerals of various origin and age. Attention should be turned not only to rare-earth minerals, but also to minerals containing small amounts of rare-earth elements. The determination of microparagenesis in the rare-earth elements of mineral deposits is also significant. These investigations will facilitate the determination of geologic relationships between various rocks formed as a result of magmatic activity and sedimentation. Moreover, they will make it possible to determine the relationship between types of rare-earth mineralization of magmatic or sedimentary origin.

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MINERAL RESOURCES OF AZERBAIJAN[1]

by

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ABSTRACT

The principal mineral resources of Azerbaijan are petroleum, iron ore, and alunites. The principal mineral regions, their history of development, and present status is summarized. --M. Russell.

Within the boundaries of the Azerbaydzhanskaya SSSR (Azerbaijan) are to be found many valuable mineral resources, of which the most important are crude oil and natural gas iron ore and alunites. In addition, there are: chrome, copper, cobalt, and cadmium ores, and deposits of barite, arsenate compounds, pyrite, bromide, iodine, rock salt, gypsum, bitumen, oil shale, basaltic rock, marble, abrasives, limestone, mineral roofing slate, mineral pigments and cement raw materials. Azerbaijan is also rich in mineral springs and medicinal muds.

The valuable mineral deposits of Azerbaijan have been extracted since ancient times. Stone mallets and chisels found in the Nakhichevan' salt mines testify to the fact that these deposits were already exploited in the stone age. In the Khanlarskiy rayon, at the Killik-Dag Peak, in the foothills of Sary-Yal, remains of ancient stone quarries have been found, with mallets weighing up to 15 kg and shaped from granodiorite and porphyrite, belonging to the neolitic age.

Historians have ascertained that the Kedabek copper ore and Dashkesan iron ore deposits were being worked during the bronze age, more than 3,000 years ago. Since there are no tin deposits in Azerbaijan, a certain portion of this metal in the composition of bronze was replaced by lead (up to 7.5 percent), zinc (up to 6 percent) and antimony.

In some of the sections of the Lesser Caucasus, especially in the zone from Dashkesan to Kedabek, and in the Nakhichevanskaya, ASSR, traces of ancient mining have also been discovered. In locations where copper deposits were worked, rock tailings and slag from copper smelting were found, and also small shafts and wells, which would permit to reconstruct the working conditions existing when the copper deposits were worked and the type of structures in the mines and pits. Articles made of iron appeared in the Azerbaijan in the 7th century B. C. and became firmly established.

The region's petroleum deposits have also been known since ancient times. Crude oil was considered one of the articles of income of the local feudal princes as well as of any foreign conquerors. In some of the archeological complexes, dating back to about 6th-8th centuries B. C., traces of tars (similar to petroleum tars) were discovered, confirming that crude oil had been extracted. The first writings attesting to oil extraction in Azerbaijan belong to the same period, and refer mostly to the Apsheronskiy Poluostrov. "Black Gold" was extracted here not only for local needs but also for export to other countries.

Azerbaijan is one of the richest regions as far as petroleum and natural gas deposits are concerned, among which the deposits on the Apsheronskiy Poluostrov with the adjoining sea areas, the Prikurinskaya Nizmennost' [Kura Depression] (Kirovabad area, Naftalan, Mir-Bashir), the Caspian Depression ("Siazanneft'"). The crude oils of the Apsheronskiy Poluostrov are characteristic by their high quality and low sulfur content, and from them are derived aviation and diesel oils and also high-grade refined products.

The larger oil fields of the Azerbaijan are located in the Baku area, where together with crude oil, combustible hydrocarbon gas is produced. These oil fields include the Baku group comprising Balakhany-Sabunchi-Ramany, Kalininskoye, Surakhany, Karachukhur, Bibi-Eybat, and also Lokbatan-Puta-Kushkan, Ostrov Artëma (island), Neftyanyye Kamni, Gyurgyany, and Binagady. West and southwest of the Baku grouping are the Kobystan oil deposits, among which the Alyaty grouping should be noted.

On the Apsheronskiy Poluostrov, the oil producing strata of Pliocene age is from 1,000 to 3,400 meters thick, averaging 2,000 meters, and is divided into two levels - the upper and the lower, consisting of layers of sand, sandstone, aleurolite[2] and clay. The upper level is sub-

[1] A translation of the Chapter Poleznyye Iskopayemyye from the book Azerbaydzhanskaya SSR, published by the Institute of Geography of the Academy of Sciences of Azerbaydzhanskaya SSR, printed in Moscow, 1957. Translation released for publication by the U. S. Atomic Energy Commission.

[2] "Alevrolit" in the source. It is a packed variety of Alevrit. Both terms were adopted in the 1930s to designate friable rock formations sometimes previously referred to (among other terms) as silts.--Translator.

divided into 4 layers, in the cross-section of which stand out more than 10 oil-bearing formations.

In the majority of cases both levels are oil bearing (the oil trusts "Leninneft'," Stalinneft'," "Ordzhonikidzeneft'"); in some sections only the lower level is oil bearing (oil trusts "Kirovneft'," "Artemneft'"). The most stable oil permeation is observed in the Kirmakinskaya and Sub-Kirmakinskaya strata of the lower level.

The Balakhany-Sabunchi-Ramany deposit, which is exploited by the "Leninneft'" Petroleum Trust, is located northeast of Baku. Its exploitation was started in 1896, when the first oil derricks were built on the Apsheronskiy Poluostrov.

At the present time three types of oil are produced: light, lubricating, and heavy fuel oil.

The Surakhany deposits ("Ordzhonikidzeneft'" Petroleum Trust), located at the Surakhany settlement northeast of Baku, have been worked since 1907. The oil from some of the strata contains paraffin and its gravity increases with depth. Closer to the surface, almost colorless oil is encountered in the Surakhany formation. At the start, only shallow lying formations of the upper oil bearing strata were worked. At the present time the Kirmakinskaya and Sub-Kirmakinskaya strata are being exploited.

The Karachukhur deposits ("Ordzhonikidzeneft'" Petroleum Trust) are located south of Surakhany. Geologically it is similar to the Surakhany deposits, being a continuation thereof of the south. Exploitation of this oil field started in 1927.

The Kalininskoye deposits ("Azizbekovneft'" Petroleum Trust) are located in the eastern part of the Apsheronskiy Poluostrov. The crude oil here is comparatively light weight. Prospecting, which was conducted here since 1904, was fruitless for a long period of time, and only in 1932 the first large gusher came in with light oil yielding up to 75 percent of benzine and kerosene. At the present time the Kalininskoye deposits are comparable to the above mentioned fields as regard to crude oil production.

The Buzovny-Mashtagi deposits ("Buzovnyneft'" Petroleum Trust) are located in the northern part of the peninsula, near settlements of the same names. These were discovered in 1940 as a result of seismographic exploration. Deep drilling established that the Buzovny dome (podnyatiye) represents a so-called buried structure, and that only the Kirmakinskaya and Sub-Kirmakinskaya formations proved to be oil bearing in the lower level of the productive strata. Here the oil is of the heavy bituminous nature.

The Binagady deposits ("Kirovneft'" Petroleum Trust) are located north of Baku. The crude oil is mostly in the lower level of productive strata and to a lesser degree in diatomic formations. Development of this oil field started in 1897.

The Bibi-Eybat deposits ("Stalinneft'" Petroleum Trust) adjoin Baku on the southwest and may be divided into two producing areas: "The old section" or coastal area occupying the marine valley, and the new oilfield - "Bukhta (bay) imeni Ilicha" in the filled coastal section of the northwestern part of the Bakinskiy Zaliv (bay) of the Caspian Sea.

The first well on the Apsheronskiy Polvostrov was drilled in Bibi-Eybat in 1848, while planned exploitation started later - in 1871; and the filled portion of the sea ("Bukhta imeni Ilicha") started to be developed only in 1922-1923. However, the fill extends only over part of the oil-bearing area under the floor of the sea, and therefore exploitation of this section of the Bibi-Eybat oil field was carried out by means of marine wells, drilled from special individual pile bases. The first marine well (first - for the entire peninsula) started producing oil in 1925.

The "Yasamalskaya Dolina [valley]" deposits are located 4 to 5 km west of Baku, and were discovered in 1933.

The Shabandagskoye deposits, discovered in the northern section of the Yasamalsakya valley in 1943, are very similar to the Yasamalskaya valley deposits.

The Lokbatan deposits are located southwest of Baku at the foot of the periodically active Lokbatan mud volcano, which, to a certain extent, is responsible for the topography and the geological structure of the area. As to the quality of the crude oil, it is very similar to that from the Bibi-Eybat field. Exploitation of these deposits started in 1932.

The Puta deposits are located southwest of Baku, and the oil produced is mostly of the heavy type. Operations were started in 1926.

The Kergez oil field is located west of the Puta deposits and is also situated in a flat valley; between them are the mud volcanoes of Kushkhan and Akhtarm. Operations were started in 1932.

The deposits on Ostrov Artëma are being exploited by the "Artemneft'" Petroleum Trust. The island is located at the eastern tip of the Apsheronskiy Poluostrov and is separated from it by the Apsheronskiy Proliv which is one to

two km wide. In 1940 a dam was built connecting the island to the mainland with a highway along the dam and later with an electric railroad. The oil produced here is heavy fuel oil. The oil pools extend far to the north and east under the sea floor. In this connection, it is here that in 1934 oil wells in large numbers were first drilled into the sea floor from individual foundations or from a trestle connected to the island.

The Gyurgyany-More [sea] deposits are located south-southeast of the Ostrov Artëma and east of Mys Gyurgyany (cape), on the easterly tip of the Apsheron Peninsula. Operations here started in 1946.

The Ostrov Zhiloy and the Neftyanyye Kamni deposits are located in the sea, at a distance of 24 to 45 km from the peninsula. The Ostrov Zhiloy belongs to the southwest wing of the big anticlinal fold. At the Neftyanyye Kamni deep drilling started in 1949, and wells are located not only on the islets but also in the sea proper. The main oil-bearing formation is the Kalinskaya, but in the southwest wing and also southeast of the Neftyanyye Kamni, the Pod-Kirmakinskaya and Kirmakinskaya formations is also oil bearing.

The Siazan petroleum deposits are 90 to 110 km northwest of Baku and stretch out in a narrow strip between Zorat and Siazan railroad stations. They belong to a steep monocline consisting of chalk and tertiary rocks, whereby the oil-bearing strata is the Maykopskaya formation. The field was opened in 1933.

The possibilities of finding oil in the Kura-Araks depression are confirmed by the Neftechala deposits and especially by the presence of oil in the areas around the city of Kirovabad. Of greatest importance here are the sections of the oil-bearing stratum of the Apsheron formation represented by clays, sands, and fairly coarse crushed rocks, and also the Maykopskaya formation.

The Neftechala oil field area is in the eastern part of the Sal'yanskaya Steppe, near the Caspian Sea, on a plain covered (as thick as 50 meters) with the sediments of the present-day and of the ancient Caspian Sea.

The geological structure of the area has been influenced by anticlinal fold stretching in the northwesterly direction and complicated by faults along its axis. Within the geological structure of the Neftechala fold, are the oil-bearing deposits of the Baku, Apsheron, and Akchagyl' formations. In the latter and in the Apsheron formation, both the oil and water contains a considerable content of iodine and bromide. Operations here started in 1931.

Of considerable size are also the deposits of Kyurovdag and Mishovdag, located in the eastern part of the Kura river depression. The wells drilled within the last few years into the productive strata uncovered extensive reserves of oil. Their large size and comparatively low depth attest to the value of these fields. Presence of oil could also be established in the formations of Kalmas, Kyursangya, Babazany, Khilly, Bolshoy and Malyy (Greater and Lesser) Kharami, and others.

Several oil-bearing areas were also discovered in the district of Kirovabad: the Kazanbulag area near the city of Kirovobad; also that of Mir-Bashir near the rayon [A soviet administrative division] center of Mir-Bashir; that of Naftalan, and others.

In some of these fields few wells were drilled and little prospecting done, and therefore, their development was suspended (as in Kazanbulag) or is being carried on only partially.

The Neftalan deposits are to the southeast from Kirovabad. The Naftalan medicinal and industrial oil, unique in the world as to its composition, is known since ancient times. Even hundreds of years ago sick people came here for cures from India, Iran, Arabia, and other distant countries. However, only after the establishment of the Soviet regime in Azerbaijan, was the oil extensively exploited.

The Naftalan crude is an oily viscose liquid, of a dark brown, almost black color, with an olive tinge, contains a negligible percentage of benzine and kerosene, and is completely devoid of paraffine, acids, etc., but includes valuable lube oils, and has a characteristic aromatic odor, which is enhanced on heating.

Balneological research established that beneficial results are obtained from "Naftalan oil baths" in case of rheumatic joints and muscles, and also in cases of women's skin and nervous diseases. A sanatorium has been built in Naftalan, where patients, coming not only from all parts of the U. S. S. R. but also from other countries, are taking cures. In industry this crude oil is used for the conservation of industrial leather and footwear. A regular type of petroleum is obtained from lower strata of the Naftalan field.

The "black gold" reserves of the Azerbaydzhanskaya SSR are quite extensive, but with the discovery of rich new reserves in the Volga basin, considerably reduced the Azerbaijan ratio in the All-Union holdings. Nevertheless, the Azerbaydzhanskaya SSR is one of the petroleum mainstays of the Soviet Union, where oil exploration and prospecting are expanding especially in the marine sectors.

Natural gases occur either together with crude oil deposits or independently. Oil shales

(Kobystan deposits near the villages of Kishlak-Ala, Sary-Dash, and Dzhangichay) are also important.

The region of the Lesser Caucasus is especially rich in ores and non-metallic minerals.

The Dashkesan deposits of magnetic iron ore are the largest in the Caucasus; based on its reserves, a large mining enterprise has been organized. The deposits are of the metasomatic contact type, and represent a layer in the contact of the Dashkesan intrusions with lime-bearing volcanic and carbonaceous rocks of the upper Jura. The deposits consist of several parcels.

Those sections of the Dashkesan deposits which have already been explored are estimated to contain up to 100 million tons with a metal content in the ore of from 40 to 70 percent.

The Alabashlinskaya group of iron-ore deposits in the Shamkhorskiy rayon represents a layer of the hydrothermal type, which is attributed to the tuff-bearing stratum of the mid-Jurassic period. The layer reaches 1.5 to 2 meters, and the average iron content in the hematite ore fluctuates between 25 and 45 percent. The reserves of the Alabashlinskiy deposits are not large, reaching about 500,000 tons for all categories [of minerals]. The area of expansion of the said hematite ores needs further exploratory research.

The titanium-bearing magnetite sandstone formations of sedimentary origin are attributed to the mid and upper Jurassic period volcanic stratum of the Dashkesan, Zaglik, Alabashly, and other locations. In the Shamkhorskiy rayon, these sandstone formations may be traced to extend, with some gaps, for 6 to 10 km. There are indications of the existence of additional iron ore deposits in this rayon of the republic.

The belt of titanium-bearing magnetite sands of the Lenkoran'-Astarinskiy coast on the Caspian Sea stretches out for 52 km, ranging in width from 50 to 200 meters, and in thickness from 1.5 to 2 meters. It has been established that, in addition to iron, the ore contains a high concentration of titanium.

The chromium ores are located mostly along the stretch of ultrabasic (iron-magnesium) formation of the central part of the Lesser Caucasus. To this zone belong the Ipyakskoye deposit in the Lachinskiy rayon, the Geydarinskoye, Zodskoye, and Dzhomartskoye deposits in the Kelbadzharskiy rayon, and the Shakhdagskoye deposit in the upper reaches of the Shamkhorchay river. The chrome oxide content in ore varies from 41 to 50 percent.

It is necessary to study further the zone of chromium-bearing ores in order to increase the proven reserves and to include them into the exploited areas in connection with the development of the metallurgical and chemical industries of the Transcaucasus.

The manganese ores of the Molladzhalinskiy and Elvorskiy deposits in the Khanlarskiy rayon are of sedimentary origin and are distributed among the upper chalk deposits. The content of manganese in the ore is about 30 percent and the iron - about 20 percent. The reserves of manganese ores are not large, and these ores may be utilized mainly in fertilizers.

The cobalt deposit of Dashkesan is one of the largest in the Soviet Union. It is of commercial significance and has been exploited for a long time. The deposits occur mostly in the form of cobalt and sulfide minerals which are found as pockets, veins, seams, and impregnations.

Copper deposits are little explored. The Kedabek deposit, which has been worked for a long time, and which once was considered the largest in the Caucasus, is now nearly exhausted. However, here are deposits of sulfur, as pyrite, in commercial quantities. The genetic and distribution link between the copper-sulfur pyrite ores of Kedabek and the quartzite porphyry of the mid-Jurassic period, together with objective geological data, suggest the strong possibility of a successful search throughout this deposit for copper ores, sulfur pyrite, and also a complex nonferrous metal ores, gold, and silver. Therefore, it is necessary to continue geological exploration work. Placer gold is encountered in the alluvium of the Terter, Gasan-Su, and Koshkarchay rivers.

The Bitti-Balakh deposit of copper and arsenic (enargite) ores, located near Kedabek, is distinctive and promising.

Of considerable interest also is the Belokany deposit of copper and magnetic pyrite (pyrrhotine), located in the northwestern part of the republic on the southern slope of the Larger Caucasus.

Large deposits of sulfur pyrite geologically similar to the Kedabek deposit are located in the Khanlarskiy rayon - the Chiragidzor and the Toganalin deposits. Ores from the Chiragidzor deposit are brought to the sulfuric-acid plant in Baku, where sulfuric acid, so necessary to the petroleum industry as well as to other industries, is produced.

Among the complex nonferrous ore deposits in the Lesser Caucasus, the Mekhmaninskaya deposits may be singled out; they contain lead and zinc in the Nagornyy Karabakh, and ores in the zone along Gyul̆yatag, Dzhanyatag, Mekhman and Trombon. The ores are in the form of nodular deposits and impregnations. The quantities of galena, sphalerite, chalcopyrite, etc., present in various locations vary greatly.

In a geochemical combination with sphalerite, are blends of cadmium. Industrial expansion is underway at the Mekhaninskiy deposit.

The Gyumyushlinskoye lead deposits in the western part of the Nakhichevanskaya ASSR (not far from Norashen village) are from the oldest rocks in the republic, Devonian. However, the period of ore deposition is considerably later than the age of the host rock. The ores appear in the form of veins, seams, and impregnations. The deposit is being work concurrent with industrial expansion.

In Nakhichevanskaya ASSR (in Ordubadskiy rayon) exploration was made for complex ores in the Agdarinskiy, Kvanusskiy, Paradashskiy, Ortakendskiy, and Bashkendskiy deposits.

Connected by origin with the Miocene Mergri-Ordubad granitoid intrusion, in a group with other mineral products, are the copper deposits of the Nakhichevanskaya ASSR (Paragachayskoye, Urumysskoye, Kilitskoye). Into the same complex of ore formations belong the deposits of andalusite and rutile, and also traces of tungsten and cobalt in Ketam and Kilit. Lead-zinc and molybdenum ore traces were found in the Keldzhabarskiy rayon near Istisu, and are now under industrial development together with the copper ore manifestations of the Bashlybel-skiy deposit. The arsenic deposit in the Dzhulfinskiy district has been widely exploited for many years. However, due to insufficient data on it, the exploitation has been suspended. Considering the value and possibilities of this deposit, it is necessary that extensive, geologic exploration operations be undertaken. There are indications also that arsenic ores exist in the Sal-varty in the Konguro-Alagez mountain range.

Among the non-metallic mineral deposits in the northeastern slopes of the Lesser Caucasus, it is necessary to mention barite which is mined from the Chovdarskiy deposit in the Khanlarskiy rayon and from the Bashkishlagskiy deposit in Shaumyanovskiy rayon.

The Zaglikskoye deposit of alunites is part of the Dashkesan ore complex and is the second richest [in ore] in the world. This deposit, of hydrothermal-metasomatic origin, is attributed to the upper Jurassic volcanic formations. On the basis of this alunite deposit, a large installation is being organized for the processing of alumina, potassium fertilizers, and sulfuric acid.

The alunite and pyrophyllite ores of Kyrvakar are the eastern continuation of the Zaglik alunite stratum; the exploitation of this deposit is quite profitable as it is located near Dashkesan.

Some of the deposits of kaolinites (refractory clays) originated from the action of hydrogaseous solutions on the quartzite porphyry and detached themselves from them in the form of seams and veins. To these belong the Zaglikskoye, Chardakhlinskoye, Karamuradskoye, Mirzikskoye, Kotulskoye and Damdzhalinskoye deposits. The Chardakhlinskoye and Zaglikskoye deposits were most extensively explored.

To the group of clays with adsorptive capacities belong the gilabi[3] -bentonite clays near the city of Khanlar, Upper Cretaceous and, on the Apsheronskiy Polustrov, Tertiary ages. They were formed from volcanic ashes.

From the interstratum waters of the petroleum districts of the Apsheronskiy Poluostrov industrial extraction of iodine and bromide has been organized. Gypsum and gazha (type of low-grade plaster or gypsum) are produced, mainly in the Kirovabadskiy and Shaumyanovskiy rayons (gazha and gypsum, respectively). Iceland spar is found near the villages of Tug and Tsakuri in the Nagorno-Karabakhskaya autonomous oblast. In the same region, near the Mirikend village, deposits of lithographic stone have been found.

Marble, except the Dashke sand variety, is found in the Norashenskiy rayon of the Nakhichevanskaya ASSR and in the Kubinskiy rayon.

Perlite, pechstein (resin stone), and obsidian, recently discovered near the health resort of Istisu is the Kelbadzharskiy rayon, serve as valuable raw material for the manufacture of heat-insulating materials, such as pumice.

Deposits of rock salt have been worked for many years in Azerbaijan near the city of Nakhichevan' (these deposits belong to the lower strata of the upper Sarmatian), as well as the natural salt deposits in the lakes and sea of the Apsheronskiy Poluostrov, such as the Masazyrskoye and Beyuk-Shorskoye deposits. Recently, large rock salt deposits were also discovered near the Negram village in the Nakhichevanskaya ASSR, lodged between sand-and-clay layers of the mid-Miocene formation. The salt-bearing layer is as thick as 80 meters.

The main exploited deposits of the Triassic period dolomites are in the Dzhufinskoye gorge of the Araks river. Some dolomite deposits have also been found in the Kobystan. To the category of facing stone materials belong the tuff formations, granitoids, Tertiary andesites and baslat, found in the Lesser Caucasus, and gabbro-teschenites in the mountainous Talysh.

In the region of Apsheron and Kobystan are bitumen and bitumenous deposits used in con-

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[3]Also spelled gilyabi - from Persian: - a type of bleaching clay.--Translator.

struction (kir, asphalt) and in the lacquer and paint industry. Another component of lacquers and paints - the copal - is encountered in the Senomanian rocks in Shaumyanskiy (Agdzhakend) and Lachinskiy rayons (Gorchu) of the Lesser Caucasus.

Mineral pigments of various origin occur in a number of places. Among them should be mentioned the Chovdarchayskaya group south-east of the city of Kirovabad, also the Bay-anskoye, Shemakhinskiye, Kelbadzharskiye and other deposits.

Review Section

Nalivkin, D. V., BRIEF ESSAY ON THE GEOLOGY OF THE U. S. S. R. Gosgeoltekhizdat, Moscow 1957, 144 p. A review by Eugene A. Alexandrov, Columbia University.

This booklet was approved by the ministry of higher education of Soviet Union as a manual for the students of geological-exploratory engineering schools and faculties. It presents in a very concise form an explanatory note to the 1:5,000,000 geological map of the Soviet Union. The information about the geomorphology, stratigraphy, structural geology, and mineral resources is summarized on a regional basis.

The Russian and the Siberian platforms, the West Siberian lowland, the Urals, Western Arctic and the Timanskiy Kryazh, Angaraean geosyncline, Central Asia, Mediterranean geosyncline, the northwestern part of the Mediterranean geosyncline, and the Pacific geosyncline are the major regional geological elements of the Soviet Union. The Paleozoic geosynclines are represented by the Urals, Angaraean geosyncline, Tien Shan, and Western Arctic. The Mesozoic and Cenozoic geosynclines consist of two enormous geosynclinal regions, the Mediterranean, and the Pacific. The Carpathians, Crimea, Caucasus, Khrebet Kopet-dag, southern ranges of Central Asia including the Pamirs, belong to the Mediterranean geosynclinal region. Eastern Transbaikalia, the region of Amur River valley, Khrebet Sikhite-Alin, Kamchatka, and northestern Siberia belong to the Pacific geosynclinal region. The Dnepr-Donets trough with the Donets Basin, Manych area, Mangyshlak, and Tuar-Kyr form a zone which is intimately related to both, the Urals and the Mediterranean geosyncline.

The Russian Platform

The Russian platform is a typical peneplain with altitudes of land surface ranging usually between 200 and 500 m. However, in the region of Khibiny-Tundra, on the Kola Peninsula, the highest point is 1, 240 m above sea level. Outcrops of Archean gneisses, migmatites, and crystalline schists occur on Kola Peninsula, in Karelia, and the Ukrainian crystalline massif. These formations are intensely folded and attain a total thickness of several thousand meters. On the Kola Peninsula, the lower Proterozoic is represented by metamorphic rocks, basic and acid effusives; the upper Proterozoic rocks are less folded and less metamorphosed. On the Ukrainian massif the lower Proterozoic is represented by the Krivoi Rog series, 1,000 m thick, which contain banded iron ores. Much study has been done on the Riphean-Sinian formations underlying the Cambrian and overlying the Proterozoic deposits. Cambrian blue clays and sandstones (20-30 m) occur northwest of the platform. Marine Lower Cambrian deposits were discovered in boreholes of Vologda, Kotlas, and Valdai, but are absent in Moscow and the eastern part of the platform. Cambrian sandstones and clays occur along the Dnestr River, in the southwest. In Russia, the Ordovician was formerly classified as Lower Silurian. Ordovician deposits occur in the Baltic region, as far east as the city of Vologda, and as far south as Vilnius. Ordovician deposits containing concretions of phosphorites occur along the river Dnestr. Bituminous shales are of great importance in Estonia and the Gdov region. The most complete sequence of Silurian deposits is found in Estonia. These deposits occur as far south as the region of Vilnius. There is no marine Lower Devonian on the Russian platform but Middle Devonian and marine Upper Devonian deposits are present in the central and eastern parts of the platform. Devonian deposits between the river Volga and the Urals contain important petroleum accumulations ("The Second Baku"). Salt domes are found in Devonian deposits north of the Caspian Sea, along the northern border of Tu Donets Basin, and in southwestern Belorussia. Lower Carboniferous deposits occur in eastern and central regions. In the Moscow Basin, Visean deposits are coal-bearing, but no coal deposits have been found north of the Moscow-Leningrad railroad. The middle and upper Carboniferous occur together over almost the entire platform. Near the Urals, lower Permian, Sakmarian and Artinskian conglomerates and sandstones attain a thickness of from 2,000 to 3,000 m. Continental and lagoonal deposits of the Kungurian stage are from 1,000 to 1,500 m thick and contain potash deposits. Upper Permian Ufa redbeds attain a thickness of 200 to 1,500 m in the Urals region. Deposits of the Kazanian stage occur in the eastern part of the platform and south from Riga, in the Baltic area. The Tatarian stage is represented by 100 to 450 m of redbeds in eastern and northern regions. Redbeds of Triassic age occur southwest of Riga and north of Orenburg. Lower Jurassic deposits occupy the northwestern strip in the Donets Basin. Middle Jurassic deposits are developed in the eastern half of the platform. The Upper Jurassic was the epoch of the greatest spread of the sea. The Lower Cretaceous occurs together with the Upper Jurassic. The Upper Cretaceous sea occupied the southern part of the platform. Chalk deposits of this age near Kharkov attain a thickness of 750 m. Paleogene deposits almost coincide with the distribution of Upper Cretaceous formations. Some 150 to 200 m of Paleogene sediments occur in

the central Volga valley. Neogene is represented by continental deposits north of the Donets Basin. Farther south marine deposits of Mediterranean type are predominant. Between the Volga and Urals are brackish-water deposits of the Aktchagylian stage. Quaternary deposits are present over the entire platform area.

There are five regional structures on the platform: the eastern and central depressions, the Baltic downwarp and the northern and southern uplifts. The eastern depression parallels the Urals and is an important petroliferous region. The central depression is underlain to a depth of 2,800 m by Devonian, Carboniferous, Permian, Triassic and Jurassic deposits. To the west, this region extends into an area of Baltic downwarping. The northern belt of uplifts consists of Precambrian and lower Paleozoic deposits of the Kola Peninsula and western Timanskiy Kryazh area. The southern uplifts are represented by the Polesyee swell, Ukrainian massif, and Yaik massif, which crosses the Ural River valley. Details are given on local structures with emphasis on salt-dome regions.

Mineral resources of the Russian platform include the iron-ore deposits of Krivoi Rog, Kursk, Kola Peninsula, and Karelia; the manganese deposits of Nikopol; nickel and copper of Kola, bauxite of Tikhvin and Onega River; oil of Urals-Volga region, Ukhta, and Emba Basin; coal deposits of Donets Basin; natural gas of Saratov; bituminous shales of Estonia and Leningrad region, and Syzran on the Volga; apatite deposits of Khibiny; nepheline of Kola, used as aluminum ore; mica and feldspar, rock salt, potash, and evaporites.

The Siberian Platform

The largest part of the platform is a plateau. The highest altitude is 2,037 m in the northwestern part of the plateau. The plains are situated at altitudes of 200 to 500 m. The stratigraphy of the platform has much in common with the Russian platform. However, the Siberian platform is characterized by an enormous area of lower Paleozoic and Silurian formations. Devonian and lower Carboniferous rocks are almost absent. Upper Paleozoic and Lower Triassic deposits are well represented on both platforms. Permian deposits in Siberia are coal-bearing. Lower Triassic traprocks occupy an enormous part of the platform. Outcrops of Archean formations occur in the regions of the Anabar and Aldan massifs, in the Patom Highlands, along the Vitim River, Baikal region, Eastern Sayan Mountains, and the Enissei massif. Proterozoic formations occupy large areas and attain a thickness of more than 20 km. Some information on Sinian deposits is included. Terse details on the stratigraphic sequence include information on the areal spread, thickness, lithology, and typical fauna of Paleozoic, Mesozoic, and Tertiary rocks. The structures are of Precambrian, Paleozoic, and Mesozoic-Cenozoic age. Magmatic activity during the Precambrian was of the geosynclinal type. During later eras, magmatism of the platform type developed. The Caledonian magmatice cycle is unknown on the platform proper, but Caledonian intrusions occur in the Olekma-Patom Highlands, Baikal region, and eastern Sayan Mountains. The Siberian trap rocks attain a thickness of 1,000 m and cover an area of about 500 km by 1,000 km. They represent effusives and subvolcanic intrusions of the Hercynian magmatic cycle. Diamond-bearing kimberlite pipes are the product of Jurassic and Lower Cretaceous, Kimmeridgian, magmatic cycle. The Alpine cycle developed effusives and subvolcanic intrusions.

Many mineral deposits are of economic interest. Iron ore deposits of upper Proterozoic age are of Krivoy Rog (Lake Superior) type. Hydrothermal iron mineralization is associated with trap rock. Siderite ores occur within the Tunguska coal-bearing formation. Nickel sulfides are associated with trap rock. Several major gold placers and primary gold deposits have been worked since pre-revolutionary time. Copper and other sulfide mineralizations containing nickel, platinum, and other metals are associated with channels leading to the trap effusives. Cupriferous sandstones occur in Upper Cambrian and Ordovician redbeds. Bauxite is found amount lacustrine Paleogene deposits and also in Lower Cambrian beds. There are enormous reserves of Jurassic and Cretaceous lignite and coal. Petroleum has been discovered in small quantity in Cambrian and Devonian deposits. Diamond deposits are associated with placers and kimberlite pipes. Mica, graphite, asbestos, semi-precious stones, and rock salt are also of economic importance.

The Western Siberian Lowland

Almost the entire surface of this, one of the largest lowlands of the world, is covered with Quaternary deposits. Its basement is at depths ranging from 3,000 to 4,000 m. The lower series of this enormous depression consists of some 2,000 to 2,500 m of Middle and Upper Jurassic, and Lower Cretaceous sediments; the middle series consist of 1,000 to 1,200 m of Upper Cretaceous and Paleogene deposits, and the upper series, 200 to 400 m thick, is composed mainly of continental deposits. The permafrost boundary is located slightly north of the maximum southern extent of continental glaciation.

The Urals

The Urals represent a typical upper Paleozoic geosyncline. The total thickness of sedi-

mentary and effusive formations is 25 to 30 km. The Ural Mountains proper consist of several north-south trending ranges 900 to 1, 500 m high. Proterozoic formations, especially in the southern Urals, attain a total thickness of 13 km. There is a suggestion of the presence of Archean and Sinian, or Riphean, rocks. Lower Cambrian reefs are found in the southern Urals. Marine Ordovician deposits are spread over the entire Urals, are 1, 500 to 2, 000 m thick on the western slope, and on the eastern slope are even thicker. Silurian formations attain 3, 000 to 4, 000 m on the eastern slope, but are somewhat thinner on the western slope. Devonian deposits consist of different facies and are thicker on the eastern slope where they attain 3, 000 to 4, 000 m. Coal-bearing Carboniferous formations attain 1, 500 to 2, 000 m on the eastern slope. Permian deposits of the western foreland depression form a sequence of 4, 000 to 5, 000 m. There are no Permian deposits on the eastern slope of the Urals. Lower Triassic deposits occur on the western slope, and Upper Triassic on the eastern. Jurassic formations are developed on both the south and north margin of the Urals. Lower Cretaceous rocks are associated with Upper Jurassic. Upper Cretaceous sediments occur along the western slope, and are especially well-developed on the eastern slope. Tertiary deposits are present on both slopes of the Urals. On the western side there is less metamorphism and the folds are simpler than in the east. The first structural stage includes Precambrian and lower Paleozoic formations; the second, middle and upper Paleozoic and Lower Triassic; the third, Upper Triassic, Lower and Middle Jurassic; and the fourth, Upper Jurassic, Lower Cretaceous and younger deposits. Deposits of the fourth stage are neither metamorphosed nor folded. The third stage forms broad regional folds with weak metamorphism and is related to the Kimmeridgian orogeny. The second stage was created by the Hercynian orogeny. Rocks of all orogenic stages are separated by disconformities. A historic sequence of tectonic movements is included together with the history of the accompanying magmatic cycles. Major ore deposits include those of iron, chromium, nickel, aluminum, platinum, and copper. Next to them in importance are potash, magnesite, asbestos, limestone and dolomite, coal, and oil. Genetic relationships of major mineral deposits are briefly outlined. However, the information given on certain aspects is obsolete, as in the case of the iron deposit of Gora Magnitnaya.

Western Arctic and Timanskiy Kryazh

This region is to a certain extent identical with the Urals. It includes the Poluostrov Taymyr, the North Siberian Lowland, Severnaya Zemlya, Franz Josef Land, Novaya Zemlya, Khrebet Pay-khoi, and the Timanskiy Kryuzh. The Poluostrov Taymyr and the archipelago of Severnaya Zemlya consist of Precambrian rocks attaining a total thickness of 15 or 20 km, covered by metamorphic Cambrian rocks and less metamorphosed Ordovician, Silurian, Devonian, and Carboniferous deposits, and Permo-Triassic trap effusives. There are some relics of Mesozoic and Cenozoic deposits. The Mesozoic and Cenozoic sediments comprise the North Siberian Lowland, which separates the orogenic structures of Taymyr and the Siberian platform. Khrebet Pay-Khoi, Ostrov Vayguch, and Novaya Zemlya are a direct continuation of the Urals. The oldest rocks are Cambrian; the youngest, Permian, while Mesozoic and Cenozoic rocks are almost unknown. The oldest rocks in Timanskiy Kryazh, Polyudov Kryazh, Kanin Nos, and Bol'shezemel'skaya Tundra are represented by metamorphic undifferentiated upper Proterozoic and Lower Cambrian rocks. In the northern Timanskiy Kryazh they are covered by Silurian, Devonian, and upper Paleozoic formations. The Devonian and younger sequence is identical to that of the western slope of the Urals and the Russian Platform. The same refers to Mesozoic and Quaternary deposits. The author considers the Timanskiy Kryazh as a northwestern branch of the Urals. Tectonics of the western Arctic is in general identical with the tectonics of the Urals. It is established that the Polar Urals are connected through Khrebet Pay-Khoi and Novaya Zemlya with the western par of Taymyr. The magmatism of Western Arctic is similar to the magmatism of the Urals. However, in Western Arctic, there are less Precambrian and Caledonian intrusions, especially ultrabasic rocks. The upper Paleozoic coal-bearing series of western Taymyr are similar to those of the Pechorskiy Basseyn.

The Geosyncline of Angara

This is the second large Paleozoic geosyncline. Its western extremity is located at the eastern slope of the Urals, and includes the depression of Turgay, eastern Kazakhstan, Altai Mountains, Kuznetsk Basin, western Sayan Mountains, Tuva, western Transbaikal region, and the regions of Yablonovyy Khrebet and Stanovey Khrebet. The Altai mountains reach altitudes of 4, 500 m and the Sayan Mountains, 2, 500 to 3, 000 m above sea level. The stratigraphic section consists of Archean, Proterozoic, Riphean and Sinian, and the entire Paleozoic sequence. The areal distribution, character of facies, and thickness of formations are indicated. It is noteworthy that the fauna of the Devonian of the Angara geosyncline is similar to the Devonian faunas of China and United States. There are almost no marine deposits in the Mesozoic sequence. Tertiary deposits are also continental. Structurally the Angara geosyncline is similar to the Uralian geosyncline. There are also four structural stages: the first includes Pre-

cambrian and lower Paleozoic; the second, middle and upper Paleozoic and lower Triassic; the third, Upper Triassic, Lower and Middle Jurassic; and the fourth, all younger non-folded and non-metamorphosed deposits. During Precambrian and lower and middle Paleozoic time, the accumulation of sedimentary and effusive rocks attained impressive thicknesses ranging from 25 to 60 km. The geosyncline was uplifted by the Hercynian orogeny, which began in the middle Carboniferous. That orogenic movements are active at the present time in the region of lake Baikal is evidenced by strong recurrent earthquakes. All orogenies were accompanied by magmatic phenomena which are discussed in chronologic sequence. Major mineral resources are the copper of Kounradskiy and Dzhezkazgan, bas metals, iron, manganese, gold, tin, mercury, tungsten and molybdenum, coal in the basins of Kuznetsk and Karaganda, lignite, bituminous shales, and non-metallic minerals, such as mirabilite, soda and fluorite.

Central Asia

In the north this region consists of a part of the Angaraean geosyncline, and in the south, part of the Mediterranean geosyncline. This area is considered as a separate geosynclinal province. The northern part of the area is a zone of deserts with plateaus 150 to 200 m above sea level. Further to the south is a zone fronting mountain ranges having a high peak of 7, 495 m. The stratigraphic sequence consists of Precambrian, Paleozoic, Mesozoic, and Cenozoic formations. In the northern mountain ranges there is a sequence 3, 000 to 5, 000 m thick of lower Paleozoic rocks. Cretaceous marine deposits attain a thickness of 1, 000 m. The piedmont deposits of Neogene age are 8, 000 to 9, 000 m thick. A thorough analysis of tectonic features includes a brief description of structural stages and substages, their evolution, superimposition, and spatial and temporal relationships from the Archean to the Quaternary. Reference is made to the formation of structural petroleum traps.

Precambrian, Caledonian, Hercynian, Kimmeridgian, and Alpine cycles of magmatic processes are well developed. The porphyry copper deposit of Almalyk is third in importance after Dzhezkazgan and Kounradskiy. Lead and zinc deposits associated with middle Paleozoic limestones are probably of sedimentary-hydrothermal origin. Other ore deposits include those of antimony and mercury, tin, tungsten, arsenic, iron and manganese, gold and some silver. Coal and petroleum form a series of economically important deposits. There is considerable fluorite, sulfur, phosphorites, and evaporites, including potash.

The Mediterranean Geosyncline

This Mesozoic-Cenozoic geosyncline is characterized by intensive Kimmerdgian and Alpine orogenies, young metamorphism and synorogenic intrusions, young mineralization, and young oil. This geosyncline includes the entire southern part of European U. S. S. R., Caucasus and the southern mountain ranges of Central Asia. The external zone of the geosyncline features the horizontal bedding of Neogene, because of absence of late phases of Alpine orogeny. On the other hand, the internal zone is characterized by a strong manifestation of early stages of Alpine orogeny and by weaker late stages of this orogeny. All formations, including the Quaternary are folded. The Dnepr-Donets depression, Manych steppe, and Mangyshlak with Tuar-Kyr on the eastern shore of the Caspian Sea are considered a foreland depression, representing a specific outlying zone of the Mediterranean geosyncline. Marine Mesozoic and Cenozoic deposits are predominant in the geosyncline. Precambrian and Paleozoic rocks outcrop in the cores of the mountain ranges. Magmatic processes are expressed by Precambrian and Caledonian, Hercynian, Kimmeridgian, and Alpine cycles. Major oil fields are located in the region of Baku and the North Caucasus; minor oil fields are known in the Carpathians. The iron ore of Kerch is one of the larger deposits of oölitic ore. Manganese occurs near Chiatura. There are also deposits of lead, zinc, silver, molybdenum and tungsten, arsenic, and good indications of radioactive ores. Large deposits of rock salt and potash are located in the Carpathians.

The Northwestern Part of the Mediterranean Geosyncline

This area includes the Dnepr-Donets and Manych depressions, and the Volga-Emba Basin. The geological position of these elements is discussed as some geologists consider them as part of the Russian Platform, others consider them as Paleozoic geosyncline, and still others consider them an outlying zone of the Mediterranean geosyncline. The last point of view is advocated by the author who supports his theory by observing that Paleozoic deposits attain a thickness of 10 to 12 km. The entire area is represented by a plain with ridges in the Donets Basin attaining an altitude of 400 m and by lowlands in the east. The oldest deposits are Devonian followed by the Carboniferous, Permian, Mesozoic, and Tertiary. Coal-bearing Carboniferous formations attain a total thickness of 8,000 to 8,500 m. The entire zone is a long narrow region of considerable downwarpings. The main orogeny was Hercynian; the Kimmeridgian orogeny is less prominent, and the Alpine orogeny is shown only by its first phase. Of particular interest are salt domes in the Emba oil fields. The Hercynian magmatic cycle is

represented by sills and Middle Devonian diabases. There are also upper Paleozoic dikes. Important coal deposits are located in the Donets Basin; petroleum, in the Emba Basin, Ukraine, and southern Belorussia. There are also important deposits of natural gas, rock salt, potash, and borates of the Inder salt dome.

The Pacific Geosyncline

This is a vast, remote, and little-studied region. The Pacific geosyncline is divided into Kimmeridgian and Alpine zones. These two zones are similar to the external and internal zones of the Mediterranean geosyncline. The Khrebet Sikhote-Alin, Sakhalin, Kamchatka, Kuril Islands, Penzhina and Anadyr river valleys, and the Koryakskiy Khrebet belong to the Alpine phase of the orogeny. The Kimmeridgian zone differs from the external zone of the Mediterranean geosyncline by stronger orogeny, synorogenic intrusions and a peculiar mineralization. The geomorphology of this part of the country is complicated. Three major geographical regions are outlined: eastern Transkaibalia, the Far East, and the North-East. Lately many stratigraphic details have been worked out. The stratigraphic sequence ranges from Precambrian to Quaternary. The first tectonic stage involves Precambrian and lower Paleozoic; the second, middle Paleozoic; the third, middle and upper Paleozoic (predominantly Hercynian orogeny); the fourth, Upper Triassic, Jurassic and Lower Cretaceous (entirely Kimmeridgian); and the fifth stage, Upper Cretaceous, Paleogene, Neogene, and Quaternary (Alpine). The magmatic processes correspond to major orogenies. The main mineral resources of the Pacific geosyncline are the noble metals, base metals, and rare metals. The coal and petroleum deposits of Sakhalin are well known.

An English version of this booklet would be a worthwhile contribution to world geology. Unfortunately it is not illustrated; cross-sections of the major geological regions would greatly improve it. A welcome suggestion has been to publish this booklet with a reprint of the geological map, scale 1:7,500,000, from the three-volume Geological Structure of the U. S. S. R., edited by A. P. Markovsky and others.

AUTHOR INDEX TO VOLUME I, 1959.

The spelling of a few names in this author index differs from the spelling given in the volume. It is believed that the spellings given here are more nearly correct. In no case is the variation so much as to cause difficulty in locating the reference in the volume.

SUBJECT INDEX TO VOLUME 1, 1959

In this index, the following words have been dropped wherever they occur as first words of a title: the, a, an, of, on.